APPENDIX A

INVESTIGATORS' REPORTS

(* - Please note: Word had some difficulties in doing proper pagination)

Barrie Bonsal:

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Large-Scale Circulation Patterns and Teleconnections Associated with the 1999-2005 Canadian Prairie Drought

Investigators: Barrie Bonsal and Amir Shabbar

1.0 Progress (beginning January 2008 to end December 2008)

1.1 **Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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.**

Theme 1:

The main objective of this study as it pertains to Theme 1 is to describe and quantify the large-scale (hemispheric/synoptic) physical factors associated with the 1999-2005 Canadian Prairie drought. During this past year, significant progress has been made toward this objective. This includes:

1. Relationships with large-scale teleconnection indices:
   - Seasonal values of the SOI, PDO, PNA, AMO, AO, and NAO have been correlated with drought indices over the Canadian Prairies (SPI, PDSI, PDSI Z-value) at various lag and lead times for the entire instrumental period of record. Preliminary results indicate several significant relationships between the drought indices and individual teleconnections such as the PDO and PNA.

   Future work will:
   - Assess whether these observed relationships for the entire instrumental period were also prevalent during the 1999-2005 Prairie drought.

- Incorporate multivariate analyses to determine if combinations of these large-scale teleconnections were responsible for the initiation, persistence, and termination of this recent drought.

2. Relationships with synoptic circulation patterns, soil moisture anomalies, and SSTs:
   - Soil moisture data, based on 0.5^{o} resolution water balance model, were used to discern warm season (April-September) soil moisture availability over North America for the 1999-2003 drought period. The one-layer model originated from the Climate Prediction Center of NOAA. Results showed that the central and western Prairie moisture deficit could be linked to the northward extension of wider dry conditions in the western U.S. During 2002, the soil moisture deficit worsened and spread eastward to cover the entire southern Prairie Provinces.
   - Analysis of circulation features over the Pacific North American sector revealed mid-tropospheric circulation patterns that were dominated by anomalous ridging over North America during the 1999-2002 warm season. A coupled mode of variability, which relates the SSTs to 500 hPa heights in the North Pacific, has been identified as an important factor in controlling these circulation features over North America.

   Future work will:
   - Assess the persistence of various atmospheric, oceanic, and land surface variables during the 1999-2005 drought.

Theme 2:
Following the quantification of the large-scale physical factors associated with the 1999-2005 Canadian Prairie drought, the main objective as it pertains to Theme 2 is to determine how these factors interacted with respect to the initiation, persistence, and termination of this drought. This will include collaboration with other researchers of the Network who are examining atmospheric physical processes and feedbacks at smaller spatial scales (e.g., John Gyakum, Kit Szeto, Ron Stewart). A better overall depiction of the physical features of this drought at a variety of scales will be provided thus, aiding in the better understanding of the processes and feedbacks acting on these scales.

Theme 3:
Not Applicable

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

Future work will:
- Assess whether observed relationships between the SOI, PDO, PNA, AMO, AO, and NAO and drought indices over the Canadian Prairies for the entire instrumental period were also prevalent during the 1999-2005 Prairie drought.
- Incorporate multivariate analyses to determine if combinations of these large-scale teleconnections were responsible for the initiation, persistence, and termination of this recent drought.
- Assess the persistence of various atmospheric, oceanic, and land surface variables during the 1999-2005 drought.

This research supports Theme 1 (quantification of the physical features of the recent drought) in that it describes and quantifies the large-scale (hemispheric/synoptic) physical factors associated with the 1999-2005 Canadian Prairie drought.

It also supports Theme 2 (improving the understanding of the processes and feedbacks governing the formation, evolution, cessation and structure of the drought) by integrating the aforementioned Theme 1 results with other DRI researchers to provide a better overall depiction of the physical features of this drought at a variety of scales and thus, aid in the better understanding of the processes and feedbacks acting on these scales.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

Statistical analyses of the various data sets are well underway. A research plan for continued analyses and integration of the results has been formulated.

2.2 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.

The impact of the project on your own institution;

Research has contributed toward Environment Canada research mandates toward the better understanding of extreme hydrologic events on the hydrology and ecology of Canada.

- **Anticipated benefits of the work for Canadians.**
  Results will aid in the Network goal toward the better understanding of drought which will benefit Canadians.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference

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

Refereed journal articles:

Bonsal, B.R. and A. Shabbar. 2008. Impacts of large-scale circulation variability on low streamflows over Canada: A review. *Canadian Water Resources Journal*, **33**, 137-154.

Conference presentations:

Bonsal, B.R., 2008. *The Drivers of Hydro-Climate Variability in Western Canada.* Past and Future Hydroclimatic Variability: Applications to Water Resource Management in the Prairie Provinces, March 17-18, 2008, Canmore, AB.

Bonsal, B.R. and A. Shabbar, 2008. Large-Scale SST Patterns and Teleconnections Associated with the 1999 to 2005 Canadian Prairie Drought. Drought Research Initiative Annual Workshop, January 17-19, 2008, Calgary, AB.

Others:

Bonsal, B.R. 2008. Droughts in Canada: An Overview. *CMOS Bulletin* **36 (3)**, 79-86.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Data are being managed by the DRI Data Manager.

Paul Bullock

2008 DRI Progress Report

Project Title: Quantifying Agricultural Drought in Western Canada

Investigator: Paul Bullock

1.0 Progress (beginning January 2008 to end December 2008)

1.2 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

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.

- MSc student, Mark Gervais, completed a two-year project and defended his thesis in December 2008 that resulted in an improved version (i.e. better accuracy) of the 2nd Generation Prairie Agrometeorological Model (PAM2nd). The revised PAM2nd will provide more accurate modeled estimates of potential and actual evapotranspiration over agricultural surfaces.
- Postdoctoral fellow, Dr. Manash Mkhabela, started compiling the final years of agricultural drought index and wheat data in September 2008. The goal is to identify those indices with the strongest correlation to wheat yield and quality, then use the indices to quantify drought extent and intensity in western Canada.

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

NA

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

NA

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

i) Drought index analysis

Dr. Mkhabela should hopefully finish assessing the agricultural drought indices in early 2009. A subset of the best indices will be targeted for the next phase of the research, below.

ii) Agricultural drought characterization, 1999-2004

In this phase of the research, a series of datasets will be utilized to characterize the spatial extent and intensity of agricultural drought over the period of interest. Statistics Canada crop yield and production data from individual census agricultural regions will be utilized to derive the spatial extent and intensity of drought across western Canada. The meteorologically-based agricultural drought indices (above) will be utilized to derive agricultural drought extent and intensity by weather station. A satellite-based characterization of agricultural drought will be conducted by a visiting scientist, Dr. Shammi Raj, in January-February 2009. The final phase will consider the correlations between these independent measurements of agricultural drought.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

- A preliminary series of meteorological-based agricultural drought indices have been tested against an observational dataset.
- The PAM2nd model has been revised and improved.
- A post-doctoral fellow has been found to conduct a full assessment of the meteorologically-based agricultural drought indices, which is now underway.
- A visiting scientist was found to conduct a remote sensing-based assessment of agricultural drought in western Canada.
- A Statistics Canada census region dataset of agricultural crop yield and production has been obtained.

2.2 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:

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**

- As a result of the work on this project, the Canadian Wheat Board, Manitoba Water Stewardship and Manitoba Agriculture, Food and Rural Initiatives have all provided cash and in-kind support to develop a system to generate real-time modeled values of soil moisture for the prairies using an expanding network of real-time weather stations for data input. Currently a proposal is before Manitoba's Agricultural Research Development Initiative (ARDI) to provide matching funds.

- **Whether and how it has improved the reliability of predictive methods;**

- Preliminary analysis has indicated that moisture demand (i.e. potential evapotranspiration) is more strongly related to wheat yield and quality than precipitation. Therefore, the improved PAM2nd model will be useful for improving the accuracy of meteorologically-based agricultural drought indices and the reliability of drought characterization based on these methods.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**

- A project got underway in September 2008 to assess the impact of growing season weather (i.e. drought) on the quality of western Canada's canola. The project is funded by the Canola Council of Canada and NSERC. The project went ahead based on work already completed showing the relationships between meteorologically-based agricultural drought indices and wheat quality. There is a similar expectation that spatial variation in canola quality can be predicted with growing season weather.

- **Any current (or potential) commercial or social applications, which the results may have;**

- Drought monitoring is normally performed using drought indices to provide decision makers with information on drought severity. In some cases, drought indices can be used to trigger drought contingency plans and financial support programs, if they are available. More accurate characterizations of agricultural drought will help improve the response to drought by various provincial and federal agencies by providing more accurate information on the extent and intensity of agricultural drought. This will facilitate a more appropriate level of response to drought and help to ensure that program payments are targeted most effectively to assist those most in need.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Saiyed, I., Bullock, P.R., Sapirstein, H.D., Finlay, G.J., and Jarvis, C.K. Thermal time models for estimating wheat phenological development and weather-based relationships to wheat quality. *Canadian Journal of Plant Science* (in press).

Bullock, P.R., Finlay, G.J. and Sapirstein, H.D. A preliminary assessment of evaporation as an agricultural drought index for spring wheat yield and breadmaking quality in western Canada. *Canadian Water Resources Journal* (submitted 23 November 2007).

Conference presentations:

Bullock, P.R. Agricultural drought assessment: an update. 3rd Annual Drought Research Initiative Workshop, Calgary, Alberta, January 2008

Gervais, M., Bullock, P.R. and Raddatz, R. 2008. Prairie agrometeorological model (PAM2nd): Calibration of Modeled Soil Water for Spring Wheat. Canadian Society of Soil Science Annual Meeting, Prince George, B.C., July 2008

Bullock, P.R. 2008. Agricultural drought. Drought Research Initiative Theme 1 Workshop, Winnipeg, Manitoba

Others:

<u>M.Sc. Thesis</u>

Gervais, M.D. 2008 Assessment of the second-generation prairie agrometeorological model's performance for spring wheat on the Canadian prairies. Dept. of Soil Science, University of Manitoba

<u>Posters</u>

Gervais, M. and Bullock, P.R. 2008. Calibration of the 2nd generation prairie agrometeorological model for spring wheat. 3rd Annual Drought Research Initiative Workshop, January 17-18, Calgary, Alberta

Gervais, M., Bullock, P.R. and Raddatz, R. 2008. Modeled evapotranspiration for spring wheat from the 2nd generation prairie agrometeorological model. Canadian Society of Soil Science Annual Meeting, Prince George, B.C., July 2008

Seminar Presentations

Bullock, P.R. A Closer Look at Weather Variability and Its Impact on Agriculture. Brokenhead Agriculture Conference, Beausejour, Manitoba, January 2008

Bullock, P.R. Quantifying Drought: How dry is it, really? Department of Entomology Seminar Series, University of Manitoba, Winnipeg, Manitoba, October 2008

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

- Agrometeorological database with surface meteorological and soil data from the NSERC wheat quality project is set up with potential online access to authorized users.
- Field books containing surface weather data, crop data and soil data from the NSERC wheat quality study (5 locations, 2003 through 2006) are available to authorized users.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

There were a series of radio interviews with Paul Bullock in October that picked on the DRI Theme 1 workshop. The interviews were centered around the state of knowledge about drought, in particular agricultural drought and its prediction.

John Gyakum

2008 DRI Progress Report

December 16, 2008:

Project Title:

Diagnostic Analyses of the Prairies Drought

Investigator:

John R. Gyakum

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1.0 Progress (beginning January 2008 to end December 2008)

1.1. Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

Theme 1: Quantify the physical features of this recent drought:
b) 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.

We address the first DRI objective of understanding of the spatial and temporal features of the recent Canadian Prairie Drought, with a study of how both atmospheric dynamic and thermodynamic processes act to modulate both the severity and length of the drought on the synoptic and sub-synoptic scales. These studies include:

1) The documentation of the modulations in the location and frequency of storm tracks.

2) An analysis of the moisture budgets for the drought region, including an examination of moisture source regions and transports.

Results achieved include:

1. Our analysis of the recent Prairie drought on seasonal time scales suggests that the drought cannot be described by a typical pattern. Rather, we find that completely different flow regimes are associated with a significant deficit in precipitation. As an example, our analysis of the spring 2001 and 2002 atmospheric circulation regimes reveals that the former period was characterized by relatively warm, dry westerly flows with a history of drying, and downsloping

winds from the Rocky Mountains. The Spring 2002 period was characterized by anomalously-cold and dry conditions associated with subsiding air on the western edge of a southeastward-traveling storm track.

2. The significant variability in the position of the mean storm track, especially during the growing season, has been documented throughout the drought. The primary characteristic is that these storm tracks were frequently displaced either to the north or south of the Prairies. Thus, it was discerned that no one teleconnection index or flow regime could account for the severity or duration of the drought. Rather, the drought was characterized by a series of differing patterns which each had the impact of limiting moisture transport into the region.
3. The role of moisture transport is found to also be important even when the transport does not directly impact the region. The recently-completed M. Sc. thesis of Alain Roberge and the submitted manuscript (Roberge et al. 2008) documenting “Pineapple Express” events (events when moisture from the tropical Pacific is transported to high latitudes) have been found to have a significant impact on the flow regimes over the Prairies. When these events occur, strong latent heat release associated with the deep tropical moisture over the western Canadian Rockies results in diabatic ridging over British Columbia. This has the impact of both displacing the mean jet to the north of the Prairies and enhancing warm temperature anomalies in the region.
4. We are continuing to monitor and analyze the sub-synoptic scale modulations in water vapor that have been documented with the network of GPS receivers currently in place near Calgary, Alberta. Our research has demonstrated the utility of these GPS receivers in quantifying the atmospheric moisture available on considerably finer time and space scales than conventional meteorological data provide. In fact, GPS receivers can be instrumental in assessing how quickly atmospheric moisture can fluctuate, providing insight into mesoscale flow regimes associated with severe convection. This can has also been shown to be useful in helping to quantifying the impact of evapotranspiration (ET) on available atmospheric moisture/stability as numerical predictions of ET in operational models are somewhat problematic. The monitoring of the water vapor fluctuations is a crucial tool in our analyses of prairie drought conditions.

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

Current research associated with Theme 2 of DRI continues to emphasize the understanding of synoptic-scale settings responsible for the initiation, maintenance, and cessation of the current drought as well as understanding the mechanisms by which precipitation and storms are modulated and their influence on drought. Our goal is to discover the atmospheric circulation regimes (if any) that are particularly pertinent to droughts in North America. We have done so with the aid of theoretical studies of blocking, with the National Centers for Environmental Prediction (NCEP) global reanalyses, and more recently, with the North American Regional Reanalyses.

To understand the large-scale settings of drought, a careful examination of the synoptic-scale flow regimes responsible for the modulation and intensity of the drought has been undertaken on weekly, monthly, and seasonal time scales. This work is designed to provide a dynamical framework for understanding the mechanisms of drought. More recent research has concentrated on detailed synoptic-scale diagnoses of vertical motions during the various phases of the drought.

Results achieved include:

1. Many previous droughts in central and western Canada have been associated with the positive phase of the Pacific North American Pattern (PNA) index. The positive phase of the PNA is associated with anomalous mid and upper-tropospheric ridging in western Canada. The subsidence accompanying this anomalous ridging generally produces fair and warm conditions over Canada west of Manitoba. Consequently, we have undertaken a study of trends in the phase and intensity of the PNA. Results indicate a significant trend in the PNA index towards positive values over the past 50 years. This is not to say that there are more extreme events of positive PNA, but rather that there is simply a higher frequency of flow regimes that are characterized by a positive phase of the PNA. If these changes are related to anthropogenically forced climate change, then it might be surmised that droughts in the Prairies may indeed become more frequent over the next several decades.
2. However, precipitation deficits at several locations, including Calgary, Edmonton and Saskatoon could not be correlated with any of the established teleconnection indices such as the Pacific North American pattern (PNA) and the El Nino Southern Oscillation (ENSO). In fact, when examined on a seasonal basis, it appears that only the spring and summer of 2004 are consistently characterized by a positive phase of the PNA.
3. The different flow regimes that contributed to the length and severity of the recent Prairies drought are being analyzed on the synoptic-scale, so that we may understand the dynamic and thermodynamic mechanisms for the precipitation deficits:

Northward-shifted jet stream and storm track

One flow regime, figuring prominently in the prairie drought climatology, is that of a storm track and associated jet stream that is shifted to the north of the prairie region. With the associated storm track also shifted northward, there are fewer synoptic-scale triggers for precipitation in the prairies. Though the large-scale setting is favorable for subsidence, because of enhanced anticyclonic shear on the equatorward side of this jet stream, we are currently studying the synoptic-scale vertical motion forcings during this regime.

Western British Columbia meridionally-oriented ridge/trough couplet

Though this flow configuration is likely to be the least intuitive among the three regimes, it logically qualifies as a drought producer, as the storm track is shifted to the south of the prairies. Most of the Prairies are characterized by anomalously low heights and temperatures during this flow regime. In fact, temperature anomalies at 850 hPa over Saskatchewan were generally 4 to 6°C below normal. The prevalence of this flow regime resulted in temperatures over the duration of the drought that were very close to the climatological average. This flow regime contributed to drought in the Prairies in two ways. Firstly, the air over the Prairies was relatively cool and stable, with significantly lower precipitable water values than the climatological average, which precluded the development of deep convection in the region. Secondly, synoptic-scale low pressure systems often developed well to the south of the Canadian Rockies, leading to a majority of the associated precipitation falling to the south and east of the Prairies. We are currently examining the details of the synoptic-scale vertical motions, in order to understand the relative importance of static stability versus synoptic-scale forcing in the maintenance of this drought regime.

Positive phase of the Pacific North American pattern.

This flow configuration has been historically associated with major droughts over the Canadian Prairies. Strong ridging over British Columbia places the Prairies in a region of enhanced differential anticyclonic vorticity advection and subsequently synoptic-scale forcing for descent. The impact of this on the sensible weather is to produce sunny and warm conditions over large parts of Alberta and Saskatchewan. This is also the pattern most likely to produce a positive feedback with respect to the drought, as the warm and dry conditions will deplete any ground moisture, which may be available. We are currently studying the detailed synoptic-scale forcing mechanisms for the descent to quantitatively validate the generally-accepted notion that anticyclonic vorticity advection drives the descent.

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

We have established the essential foundation for a significantly-improved understanding of the 1999-2004 Prairie Drought. We will build upon this foundation with continuing detailed synoptic analyses of vertical motions and moisture budget analyses associated with the generation, maintenance, and decay of the relevant circulation regimes associated with the various components of the drought.

We are building upon the recently-completed work of Roberge et al (2008) on moisture transports, particularly the "Pineapple Express" to focus on the details of how strong latent heat release effects diabatic ridging, and the displacement of the mean jet to the north of the drought region.

We intend to continue our research on the relationship of the secular changes in atmospheric circulation regimes to regional climate change, and the associated phenomena of droughts.

We will continue to monitor the details of GPS-derived precipitable water to provided crucial sub-synoptic-scale information to enhance our understanding of the impact of evapotranspiration (ET) on available atmospheric moisture/stability as numerical predictions of ET in operational models are somewhat problematic.

All of the above projects address the goals and objectives set out in DRI Themes 1 and 2.

2.0 <u>Impact</u>

2.1 What short and medium term objectives have been achieved, or are anticipated;

The objectives achieved are discussed in section 1.1 above.

2.2 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:

- **Anticipated benefits of the work for Canadians.**

Our project has continuing relevance for Dr. Gyakum's participation with the GEOIDE network project of Dr. Susan Skone of the University of Calgary. Our research using the GPS data, promises to enhance our understanding of sub-synoptic evapotranspiration processes in regions prone to droughts.

The Pineapple Express research described above is primarily funded by Dr. Gyakum's NSERC Discovery Grant.

The research on secular changes in atmospheric circulation regimes and extremes has been funded in part by an NSERC Discovery Grant for Ph. D. student, Ms. Jessica Cox.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles related to this Grant:

Roberge, A., J. R. Gyakum, and E. Atallah, 2008: Analysis of intense sub-tropical moisture transports into high latitudes of western North America. *Wea. Forecasting*, submitted.

Conference presentations and seminars related to this Grant:

John Gyakum's presentations:

1. "Regional climate issues in the context of global change"

   University of Calgary, Department of Geomatics - March 27, 2008

2. "Synoptic modulation of the Prairies drought (1999-2005)"

   Drought Research Initiative (DRI) Workshop #3; Calgary, AB, January 17 – 19, 2008.

Post-doctoral fellow conference presentations:

3. Atallah, E., oral presentation**,** entitled "Synoptic modulation of the Prairies drought (1999-2005)". Drought Research Initiative (DRI) Workshop #3; Calgary, AB, 17-19 January 2008.

4. Atallah, Eyad, oral presentation, entitled "Global impacts of the extratropical transition of Hurricane Noel (2007)'. American Meteorological Society 28th Conference on Hurricanes and Tropical Meteorology. Orlando, FL, April 30, 2008.

5. Atallah, Eyad, oral presentation, entitled "Synoptic modulation of the Prairies drought (1999-2005)". CMOS, Kelowna, BC, May 26, 2008.

Graduate student conference presentations:

6. Cox, Jessica, oral presentation, entitled ‘Intense regional climate change in northwest Canada’, European Geophysical Union, Vienna, Austria, April 18, 2008.

7. Knowland, Katherine Emma, oral presentation entitled ‘A study of the meteorological conditions associated with anomalously early and anomalously late openings of a Northwest Territories winter road. The Fifth Interdisciplinary Graduate Student Research Symposium (IGSRS), McGill University, April 3, 2008.

8. Knowland, Katherine Emma, oral presentation entitled ‘A study of the meteorological conditions associated with anomalously early and anomalously late openings of a Northwest Territories winter road. CMOS, Kelowna, BC, May 26, 2008.

9. Roberge, Alain, oral presentation, entitled ‘Analysis of intense sub-tropical moisture transports into high latitudes of western North America’. CMOS, Kelowna, BC, May 26, 2008.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Our primary data sources include the NCEP global and regional reanalyses, which are both freely available to all researchers.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

We are in the process of providing outreach workshops to northern communities in association with John Gyakum’s IPY research projects. It is expected that drought research will be discussed at these workshops.

John Hanesiak

2008 DRI Progress Report

Project Title: SURFACE-ATMOSPHERE COUPLING DURING DROUGHT AND CONVECTIVE EVENTS

Investigator: JOHN HANESIAK

1.0 Progress (beginning January 2008 to end January 2009)

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2007-2008. How are the original milestones being met? List the key objectives and results achieved to date as well as any relevant application(s) of the results.

My overall project objectives have not changed over the past year.

Project Objectives:
(1) examine the linkages between surface characteristics and other atmospheric forcing on deep convective activity (initiation and rainfall) during the drought period.
(2) examine regional climate model simulations of drought toward improved prediction

The methods to address objective 1 will fall under Themes 1-3 (via characterizing the drought, improve process understandings and modeling experiments) and Theme 2-3 for objective 2.

Theme 1 *(Drought Characterization)***:**

(related to Hanesiak Objective 1):

- We have completed the generation of figures in relation to the spatial and temporal larger scale characteristics of the drought through mapping several drought indices (monthly PDSI and SPI), monthly precipitation and temperature anomalies using the CanGrid dataset (anomalies calculated using the standard 1971-2000 means), prairie wide daily soil moisture and ET patterns using the PAM-II crop model as well as daily and monthly maps of lightning. Some select animations have been produced. This work has been completed by my two PhD students Julian Brimelow and Hassan Bhuiyan and the help of two undergrad students funded by DRI (Dan Battencourt and Justin Hobson).
- Work is ongoing to examine convective activity in association with wet/dry areas identified by the crop model and other maps generated above by an undergraduate honors thesis project (Jeremy Kusyk) as well as my Ph.D. student Brimelow.
- This has been the extent of Year 1 activity and follows the timelines set up in the original proposal for the most part. Some minor delays have been encountered due to unforeseen issues with plotting lightning data, however, this has been resolved.

Theme 2 & 3 *(Improved Process Understanding and Prediction)***:**

(related to Hanesiak Objective 1):

- In collaboration with Richard Raddatz (U. Manitoba), we have identified the key convective and non-convective forcing mechanisms during the drought and one non-drought year (2000-04) (this work was published this year : Raddatz, R.L. and J.M. Hanesiak, 2008: Significant Summer Rainfall in the Canadian Prairie Provinces: Modes and Mechanisms 2000 – 2004, Intl J. Climatology, DOI: 10.1002/joc.1670. This work was not directly funded by CFCAS but has relevance to DRI.
- In collaboration with my graduate student (An Tat) and Raddatz, we quantified the ability of using soil moisture as a seasonal predictor of summer severe weather on the Canadian Prairies (This work was published this year : Hanesiak, J., A. Tat and R.L. Raddatz, 2008: Initial Soil Moisture as a Predictor of Subsequent Summer Severe Weather in the Cropped Grassland of the Canadian Prairie Provinces, Intl J. Climatology, DOI: 10.1002/joc.1743). This work was not directly funded by CFCAS but has relevance to DRI.
- Brimelow has recently submitted a paper (CFCAS funded) which investigates the utility of adopting a multi-model ensemble approach to quantify the uncertainty in modeled ET and root-zone soil moisture. These uncertainties can arise from variability in soil composition and the different techniques used to estimate the water retention characteristics of soils. The modeled data were validated against in-situ observations of soil moisture for three DroughtNet sites in Alberta. Our major findings were: (a) There is merit in the multi-model ensemble technique for quantifying both the uncertainty associated with the forecasts; (b) the multi-model technique is also effective in reducing the forecast error of root-zone soil moisture, and (c) the modeled root-zone soil moisture are generally in excellent good agreement with the in-situ observations.
- Brimelow is currently writing another paper (CFCAS funded) in which we investigate the accuracy of the modeled ET estimates from PAMII. To this end we used daily ET derived from two eddy covariance (EC) systems—one located over a barley crop for a single growing season,

and a second system located over a short-grass prairie site (for three contrasting growing seasons). The data analyses have demonstrated that: (a) PAMII is skillful at modeling the day-to-day variability in ET; (b) PAMII is capable of capturing the difference in ET above two contrasting vegetation types; (c) PAMII simulates the contrasting ET observed in wet versus dry years.

- The EC data have also afforded us the opportunity to calculate the canopy resistance term. This term is critical in modulating ET and is also a critical term in PAMII. Preliminary results suggest that there is a significant difference in the partitioning of incoming solar energy and the canopy resistances over the cereal crop and short-grass prairie. These data will be used to further improve and refine PAMII; our findings will be soon be submitted as a research note (CFCAS funded).
- This work provides confidence in the crop model's ability to spatially and temporally represent and predict soil moisture and ET quite well over the growing season, and will be used in future work to examine more closely these process linkages to atmospheric convection initiation.
- Some of this work has been presented at the annual DRI meeting in 2008 and up to date work will be presented at the Annual DRI workshop in January 2009.
- Brimelow and Hanesiak also participated in the UNSTABLE project in central Alberta during July 2008 with the goal of investigating wet/dry areas in convective processes. Some DRI funds were used to participate in UNSTABLE (approved by the DRI BoD). Unfortunately, 2008 was very wet in central Alberta with relatively homogeneous soil moisture conditions across the region. It is for this reason that we do not foresee using UNSTABLE data in Brimelow's Ph.D. work in relation to DRI.

Theme 3 *(Improved Prediction)***:**

(related to Hanesiak Objective 2):

- CRCM hindscast output was acquired for an older model run (CRCM using a force restore surface scheme) and CRCM coupled to CLASS. There are many model parameter outputs, however, we have focused mainly on precipitation and temperature thus far.
- To gain confidence on the ability of CRCM; two variables, precipitation and temperature are validated with adjusted observed Canadian gridded (CANGRID) data. Experiments using different version of CRCM are also examined to see whether a sophisticated land surface scheme improves the prediction of model's surface variable. Overall, the CRCM coupled to CLASS reproduces these fields much more accurately than the non-CLASS version, both spatially and temporally.
- In order to make best used of climate model data, two distributed hydrology models have been selected for this study: (i) The WEATFLOOD, developed as the University of Waterloo, and (ii) The Variable infiltration Capacity (VIC) model. The Burntwood river watershed, located approximately 25km southwest of Thompson, is selected for hydrological assessment of the study. Climatilogical and hydrological data have been collected and examined for the basin. Other area specific information, like digital elevation model (DEM), land cover maps are also collected and pre-processed in order to perform a test run using WATFLOOD. The VIC model has been downloaded and compiled. A trial run of VIC has been performed using test data.
- At this point of study, the WATFLOOD hydrology model calibration is in progress. Once, the model calibration and validation is over. The validated model will be used to perform scenario

run for hydrologic change assessment. In addition to the Burntwood river watershed, two other watersheds will be selected. The calibrated model parameters will be extrapolated to the additional watersheds to test the transferability of model parameters.

- Some of this work was presented at the annual DRI workshop in 2008 with more up to date work being presented at the annual DRI workshop in January 2009.
- All of this work is being done by Hassan Bhuiyan (PhD student).

1.2 **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.**

We will continue as planned for Brimelow's work on identifying wet/dry soil moisture and ET areas using the PAM-II crop model over the Prairie-wide region and linking these areas to convective cloud initiation, lightning and storm development. Related work being done by an honors thesis student will also be completed by May 2009. Collaborations with Masaki Hayashi, Paul Bullock and Rick Raddatz will continue with this work.

We will also continue work as planned with Bhuiyan on historical CRCM simulations over the DRI period as well as other drought periods, with a primary focus on precipitation and hydrological modeling over specific basins of interest. A climate change scenario can be use as input to a hydrology model for impact assessment in order to provide an estimate of changes that may occur in the future. Since this study focuses on regional change assessment, two CRCM experiments (one using present climate and one using future climate) are used to develop change scenarios. Synthetic scenarios, by altering historical time series, will also be constructed for use in this study along with the CRCM generated scenarios. Collaborations with Ouranos and Manitoba Hydro will continue for this work.

2.0 <u>Impact</u>

2.1 What short and medium term objectives have been achieved, or are anticipated;

- We have produced 2 publications about forcing mechanisms associated with significant rainfall (Theme 2 objective) and seasonal predictions of severe weather using soil moisture (Theme 3 objective). These papers were not directly funded by CFCAS but are relevant to DRI.
- We have submitted a journal article (Brimelow CFCAS funded) focusing on using an ensemble approach to modeling/predicting soil moisture and ET under various soil and vegetation regimes.
- We have produced graphics/animations of precipitation, temperature, soil moisture and ET conditions over the drought period using various datasets to characterize the drought, a Theme 1 objective.
- We have also begun to investigate how well the CRCM is able to simulate drought as well as begun to apply hydrologic models over the region, a Theme 3 objective.

2.2 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.

We have developed direct collaborations with Civil Engineering (Manitoba) who are working on a water and climate change NSERC project with Manitoba Hydro and Ouranos. We are in the process of developing a research proposal centred around DRI science focused on Manitoba Hydro water issues with major funding potentially coming from MB Hydro and NSERC.

3.0 <u>Dissemination</u>

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.

Refereed Articles:

Brimelow, J.C., J.M. Hanesiak, and R.L. Raddatz, 2009: Validation of the Canadian prairie agrometeorological model and an examination of its sensitivity to soil hydraulic parameters using ensembles. In review, Journal of Agricultural and Forest Meteorology.

Hanesiak, J., A. Tat and R.L. Raddatz, 2008: Initial Soil Moisture as a Predictor of Subsequent Summer Severe Weather in the Cropped Grassland of the Canadian Prairie Provinces, Intl J. Climatology, DOI: 10.1002/joc.1743

Raddatz, R.L. and J.M. Hanesiak, 2008: Significant Summer Rainfall in the Canadian Prairie Provinces: Modes and Mechanisms 2000 – 2004, Intl J. Climatology, DOI: 10.1002/joc.1670

Conferences:

(oral) Brimelow, J. et al, "Verification of PAM-II against in-situ soil moisture and eddy-covariance data: model sensitivity to soil hydraulic parameters and minimum stomatal resistance", 42nd annual CMOS Conference, Kelowna, BC, May 25 – 29, 2008

(poster) Bhuiyan, H. et al, "Drought over Canadian prairies: CRCM data validation during 1999-04", 42nd annual CMOS Conference, Kelowna, BC, May 25 – 29, 2008

(poster) Brimelow, J. et al, "Verification of PAM-II against in-situ soil moisture and eddy-covariance data: model sensitivity to soil hydraulic parameters and minimum stomatal resistance", 3rd annual DRI workshop, Calgary, AB, Jan. 17-19, 2008.

(poster) Bhuiyan, J., "Drought over Canadian prairies: CRCM data validation during 1999-04", 3rd annual DRI workshop, Calgary, AB, Jan. 17-19, 2008.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

none

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

none

Masaki Hayashi

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title:

Investigator: Masaki Hayashi

1.0 Progress (beginning January 2008 to end December 2008)

1.1. Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

Theme 1: Quantify the physical features of this recent drought:
c) 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.

Theme 1 (20 %)
A brief survey of the Alberta Environment Groundwater Observation Well Network (GOWN) indicated that the groundwater level was steadily going down in some regions, presumably due to over pumping, and the effects were particularly pronounced during the drought. We started a case study examining the relation among groundwater level and water usage at two locations, Irricana and Acme in southern Alberta. The study showed that the steady water level decline at these two areas were primarily caused by over-pumping, even though they rarely exceeded the licensed pumping rates. This points out a need to use an integrated approach, rather than the well hydraulics alone, considering the anthropogenic effects as well as meteorological forcing in the water management during droughts.

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

Theme 2 (70 %)
We continued with the detailed process study at the West Nose Creek watershed focusing on; 1) snowmelt, 2) evapotranspiration, and 3) soil water balance and groundwater recharge. For snowmelt processes, the data analysis showed the importance of sensible heat inputs for mid-winter snowmelt events driven by the Chinook. For evapotranspiration and soil water balance, the flux data collected by an eddy covariance system indicated that plant roots tend to access deeper soil water as the surface soil becomes dry, resulting in the upward flow of soil water from the water table. A paper summarizing these findings has been submitted to the DRI evaporation special issue of Canadian Water Resources Journal.

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

Theme 3 (10 %)
Our objective for Theme 3 is to develop a groundwater recharge model and couple it with existing groundwater flow model. The coupled model will provide an effective tool for the prediction of drought impacts on groundwater resources. We selected the Versatile Soil Moisture Budget (VSMB) model as a prototype of recharge model. The VSMB is used operationally by the DRI partners, Alberta Agriculture and Rural Development (AARD) and Prairie Farm Rehabilitation Administration (PFRA). Therefore, any improvement made on the VSMB by DRI will directly benefit these partners. Using the field data collected at the West Nose Creek watershed, we have made improvements in evaporation and snowmelt modules of the VSMB, incorporating our results in Theme 2. Summary of the improvements is reported in the paper submitted to the DRI evaporation special issue (see above).

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

We will continue to conduct process studies and data analysis at the West Nose Creek watershed (Theme 2), further improve the VSMB (Theme 3), and start coupling it with a groundwater flow model. We will also expand the case study on groundwater level change before, during, and after the drought (Theme 1). The expected results will improve our understanding of the feedback among meteorological forcing, soil moisture, and groundwater. The improved understanding will feed into integrated models of surface water and groundwater, which will be used to examine the response of surface and groundwater resources to meteorological forcing during droughts.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

We made significant progresses in understanding the processes governing the exchange of water and energy between the soil and atmosphere, and how they affect groundwater. The new understanding is being incorporated in a groundwater recharge model.

2.2 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);**

As part of the DRI project, we developed the methodology for implementing locally-based groundwater monitoring network in the West Nose Creek pilot study. The methodology has been adopted by the MD of Rocky View (see above, Section 1.5). The MD of Foothills is interested in adopting a similar approach, and I made a presentation to the MD Council Meeting of Foothills in September 2008.

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**

We are working with AARD and PFRD, both DRI partners, to improve the VSMB model.

- **Whether and how it has improved the reliability of predictive methods;**

Our study will result in the improved reliability of the VSMB model.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Conference presentations:

Hayashi, M. and van der Kamp, G. Groundwater-wetland ecosystem interaction in the semiarid glaciated plains of North America. Annual Meeting of the Canadian Geophysical Union, Banff, May 11-14, 2008.

Xu, L., Hayashi, M., Jackson, J. and Bentley, L.R. Estimating groundwater recharge under upland and depression using a simple soil water balance model. Annual Meeting of the Canadian Geophysical Union, Banff, May 11-14, 2008.

Hayashi, M. and van der Kamp, G. Effects of depth-permeability distribution on groundwater exchange and water balance of prairie wetlands. Ninth Joint Groundwater Specialty Conference of the International Association of Hydrogeologists - Canadian National Chapter and the Canadian Geotechnical Society, Edmonton, September 21-24, 2008.

Wozniak P.R.J., Hayashi, M., Bentley, LR., Grasby, S.E. and Eckfeldt, M. Characterization of the Paskapoo for sustainable groundwater development: A modeling approach. Ninth Joint Groundwater Specialty Conference of the International Association of Hydrogeologists - Canadian National Chapter and the Canadian Geotechnical Society, Edmonton, September 21-24, 2008.

Hayashi, M. and van der Kamp. G. Interaction of groundwater with prairie wetland ecosystems in Canada. 36th Congress of the International Association of Hydrogeologists, Toyama, Japan, October 26-31, 2008.

Others:

Jackson, J.F. 2008. A soil water balance and potential recharge study in the north-west Canadian prairies. M.Sc. thesis, University of Calgary.

Eckfeldt, M. 2008. Sustainable groundwater in Alberta: Assessing the effectiveness of the Q20 method in determining safe well yields for Acme and Iricana. B.Sc. thesis, University of Calgary.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

We provided our field data from West Nose Creek to Dr. Al Woodbury's group and Dr. John Hanesiak's group in previous years. We received no data requests from DRI investigators this year. The data are temporarily archived in our computers in Calgary, and being quality controlled for wider distribution. The data will be made available any time upon request.

Henry Leighton

2008 DRI Progress Report

Project Title:

Investigator: Henry Leighton

1.0 Progress (beginning January 2008 to end December 2008)

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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. Drought Characteristics (Theme 1)

One of the goals of the present work is to understand the relationship between precipitation anomalies and cloud anomalies. Accordingly, the Standardized Precipitation Index (SPI) was used to categorize months in 5 classes ranging from extremely dry to extremely wet. The SPI was calculated from CANGRID monthly precipitation for the period 1950 – 2004.

a) For the period from September 1999 to December 2004 we determined the number of months that 1^o x 1^o grid squares were "dry" or "exceptionally dry". It was found that the regions that had the most months in each of these categories were concentrated in central Alberta and to the west of the Alberta – Saskatchewan border. Some other regions of the Prairies had fewer than the expected number of months in these categories.
b) Seasonally, the fall and winter periods (Sept. – Feb.) had more dry moths than the spring and summer seasons.

2. Cloud and Radiation Characteristics (Themes 1 and 2)

Cloud and radiation data were obtained from the ISCCP SRB datasets. The period 1999-2004 is too short to determine relationships between cloud properties and precipitation and so the study was extended to look at the relationship between precipitation and clouds over the Prairies for the 20-year period 1984 – 2004.

a) Cloud amounts were averaged for each month and over all 1^{o} x 1^{o} grid squares classified by SPI. There was a small but clear trend for drier months to have less cloud cover for all months except in January and February but it is known that the ISCCP cloud data are not reliable over snow-covered surfaces. Similar trends were found for the cloud anomaly during the periods May – Sept. when the boreal forest and southern agricultural regions were examined separately, with cloud cover being about 10% greater during severely wet months than severely dry months.
b) Although there is a definite relationship between cloud amount and precipitation, there was a large variability with coefficients of determination (r^2) ranging between 0.1 and 0.31for individual months.
c) There was considerable spatial variability in the summer cloud amount anomaly for both severely wet and severely dry conditions. For severely dry conditions the largest negative anomalies were in the western portion of the domain whereas for severely wet conditions the southern portion of the Prairies had greater positive cloud amount anomalies than the northern regions. The cloud amount anomaly for dry months in the recent drought (1999-2004) did not follow the pattern for 20-year dataset just described. For the recent drought period in dry months the greatest negative cloud anomalies were in central Alberta and the southern portions of all three Prairie Provinces.
d) The analysis described in a) was repeated with clouds classified as high, medium and low. High and medium clouds each followed the trend of smaller cloud amounts for drier months but low clouds showed the opposite trend. There were greater low cloud amounts in drier months than in wetter months. This may be at least in part an artifact since as high and medium cloud amounts diminish more low cloud becomes visible to the satellite. (The trends also broke down in the winter months probably for the reason suggested previously that the cloud amounts over snow-covered surfaces are unreliable.)
e) Thin clouds were about 15% more prevalent during severely wet months than severely dry months and the converse was true for medium clouds which were about 15% more prevalent in wet months. These results pertained to the sub-regions identified as Boreal Forest and Agricultural Land, and also to the whole Prairie region for the 1999-2004 period.
f) There is an inherent uncertainty in the extraction of cloud amounts from satellite data. Furthermore, cloud thickness in addition to cloud amount will be a factor that relates to precipitation amount. Accordingly, regressions between TOA albedo and SPI were

examined. Similar relationships between SPI and TOA albedo were found as for cloud amount and SPI but the values of r^2 were significantly greater. However, it must be noted that the TOA albedo data are only available for daylight hours whereas the cloud amount data are also available for daytime and nighttime hours. So some of the differences in the regressions could be due to diurnal effects.

g) Analyses of the precipitation – cloud and precipitation – TOA albedo relationships for individual 1^o x 1^o grids in northeastern Alberta and southwestern Saskatchewan produced results that were consistent with those described above for the whole region.

3. Comparisons of Observations and CRCM Simulations (Theme 3)

a) The annual precipitation and May – October precipitation averaged over the whole study domain for the period 1999-2004 from the CRCM agreed well with CANGRID data. The CRCM overestimated the annual precipitation by about 3% and the May – Oct. precipitation by about 2%. In the southern portion of the domain excluding the Rockies, where the precipitation measurement network is densest, the model underestimated precipitation by 7% over the full year and 5% in May to Oct.
b) The spatial distribution of the frequency of drought months (SPI < -0.5) and severe drought months (SPI < -1.5) in the period 1999 – 2004 from the CRCM simulation shows similarities to the distribution from the CANGRID data. The area of the region with the most drought months is smaller in the simulation than that from CANGRID.
c) Differences between the 20-year average monthly mean cloud amounts from the model and satellite data vary spatially within the domain. Ignoring the winter months because distinguishing snow from cloud in the satellite data is a problem, in the southern Prairies the CRCM underestimates the monthly mean cloud amount by between 5 and 10%. In the Rockies the agreement is better but in the northern Prairies the CRCM overestimates the cloud amounts from July – October compared to the satellite data.
d) The model average monthly mean cloud anomalies stratified into 5 classes according to SPI (severe drought to severe wet) showed a much greater dependence on SPI than did the anomalies deduced from the satellite data. Furthermore, the coefficient of determination (r^2) for the regression between cloud anomaly and SPI was significantly larger for the model than the satellite data.
e) In the recent drought period the mean cloud anomalies for conditions when SPI ≤ -0.5 were typically about 5% greater (more negative) in the model results than from the satellite data. Also, the spatial distributions of the anomalies in the model and from the satellite data were quite different. In the model the largest (most negative) anomalies were in southern Alberta and central Saskatchewan. From the satellite data

the largest anomalies were in southern and central Saskatchewan and southeastern Manitoba.

Our original milestones have been met.

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:

Theme 1: Quantify the physical features of this recent drought:
d) 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.

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

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

1.2 **Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.**

We will continue to compare the results from the CRCM with satellite observations.

We will compare the ISCCP products that we have been using with MODIS cloud data in order to estimate the reliability of the ISCCP products in this region.

We will look for evidence of a connection between increased aerosol optical depths and reduced precipitation.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

We have characterised the drought in terms of cloud anomalies and albedo anomalies.

We have determined correlations between clouds and precipitation and between albedo and precipitation that should be reproducible by models that are being used to understand and predict drought. The relationships that we have found should provide a useful constraint on the models.

2.2 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:

- **Whether and how it has improved the reliability of predictive methods;**

  See 2.1.

3.0 <u>Dissemination</u>

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles: Drought and Associated Cloud Fields over the Canadian Prairies by Heather Greene, Henry G. Leighton and Ronald E. Stewart has been submitted to Atmosphere-Ocean.

Conference presentations: Analysis of Cloud Fields During the Recent Prairie Drought by Heather Greene, Henry Leighton and Ronald Stewart. Presented by Heather Greene at the CMOS Congress, Kelowna, B.C. 2008.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

NA

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

None

Charles Lin

2008 DRI Progress Report

Project Title: Soil moisture analysis and seasonal forecast of drought

Investigator: Charles Lin

1.0 Progress (beginning January 2008 to end December 2008)

1.2 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2007-2008. How are the original milestones being met? List the key objectives and results achieved to date as well as any relevant application(s) of the results.

Theme 1 (0%):

Theme 2 (0%):

Theme 3 (100%):

For our DRI contributions, we build upon our experience over the past decade on the coupling of atmospheric and land surface hydrological models for flood and drought simulation. This has been done over different watersheds in Canada (e.g., Gatineau, Chateauguay, Saguenay, Liard, and 11 Prairie basins) and China (e.g., Huaihe River Basin and 43 others), for both climatological and extreme events. We apply the coupling methodology and experience that we gained in flood simulation and real-time forecast to DRI, by using the Variable Infiltration Capacity (VIC) model for soil moisture analysis and real-time drought monitoring and forecast over the Prairies. Additional results include the analysis of seasonal forecast of droughts using the Canadian global climate model GCM3 (which is couple to the land surface scheme CLASS), and further work with CLASS and gCLASS; the latter is the groundwater version of CLASS developed by Alan Woodbury's group. We note both GCM3 and the Canadian Regional Climate Model (CRCM) have CLASS as their land surface scheme. Each of these aspects will be described in more detail below.

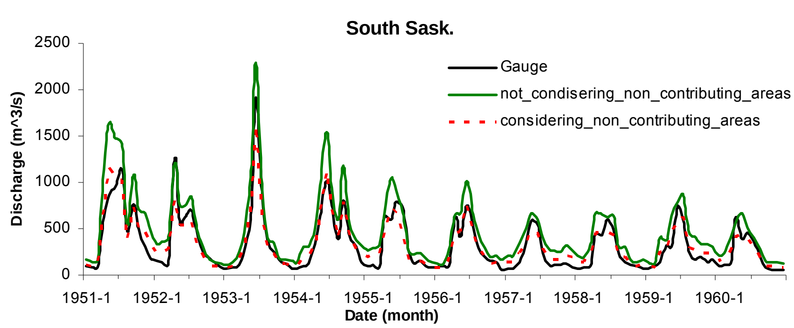
Real time flood forecast in China

In Lu et al. (2008, Science in China Series E: Technological Sciences, doi:10.1007/s11431-008-0093-x), we apply a coupled hydro-meteorological modeling system for real-time flood forecast and flood alert over the Huaihe River Basin in China. The system consists of the mesoscale atmospheric model MC2 (Canadian Mesoscale Compressible Community) that is one-way coupled to the Chinese Xinanjiang distributed hydrological model, a grid-based flow routing model, and a module for acquiring real-time gauge precipitation. The system had been successfully tested in a hindcast mode using 1998 and 2003 flood cases in the basin, and has been running daily in a real-time mode for the summers of 2005 and 2008 over the Wangjiaba sub-basin of the Huaihe River Basin. The MC2 precipitation combined with gauge values is used to drive the Xinanjiang model for hydrograph prediction and production of flood alert map. Our real-time precipitation and flood forecasts are used as operational guidance by the Bureau of Hydrograph, Ministry of Water Resources in China. Such guidance has proven very useful for the Office of State Flood Control and Drought Relief Headquarters in operational decision making for flood management. We apply the coupling methodology and experience gained to develop a real-time drought monitoring and forecast system for the Prairies in DRI.

Soil moisture analysis over the Canadian Prairies

The characterization of agricultural drought is an important task in DRI, but its quantitative definition is a challenge. Soil moisture is an important consideration in this regard. We have used the VIC model to simulate daily soil moisture over a 35-year period (1971-2005) for China, with a spatial resolution of 30 km. (Wu et al., 2007). Using this methodology, we have successfully reconstructed a data set of 56-year (1950-2005) daily soil moisture values for three soil layers (0-20 cm, 20-100 cm, and 0-100 cm) for the Canadian Prairies (1,964,000 km^2). VIC is applied over a grid of 4,393 points with a resolution of 0.25º × 0.25º, and is driven by daily maximum and minimum air temperature and precipitation from 1,167 meteorological stations. VIC is first calibrated and validated with daily hydrographs from 11 Prairie catchments with drainage areas ranging from 3,750 to 131,000 km^2 for the period 1 January, 1975 to December 31, 2001. The calibrated VIC is then used to reconstruct daily soil moistures over the Prairies for the period 1 January, 1950 to 31 December, 2005. The VIC moisture values are then used to calculate the Soil Moisture Anomaly Percentage Index (SMAPI) as an indicator of the severity of agricultural and hydrological droughts. A novel feature is the consideration of non-contributing drainage areas in the calculation of model runoff. Figure 1 shows a comparison of simulated and observed hydrographs at the outlet of two catchments, with and without consideration of non-contributing drainage areas. We see a significant improvement of the results when the latter is taken into account.

Figure 1: Comparison of model and observed hydrographs at the outlet of the South Saskatchewan catchment (top panel). The model values are from VIC, simulated with and without consideration of the effect of non-contributing drainage areas in the model runoff calculation. The bottom panel is for the Assiniboine catchment.



Our study is the first attempt in Canada to systematically reconstruct daily historical soil moisture conditions for the Prairies using a macroscale hydrology model. A paper reporting these results, co-authored with John Pomeroy, is in the final stages of revision and will be ready for submission in early 2009.

We have also gained significant experience in precipitation analysis and model verification. Slavko et al. (in final preparation, to be submitted in early 2009) examined hourly precipitation fields from the GEM and Eta weather prediction models and compared them with radar observed fields in the central and eastern US. A multi-category verification methodology for the frequency distribution is used, which gives a more complete description of the error characteristics than conventional approaches. This statistical methodology will be used to examine precipitation in the Prairies as well as soil moisture distributions. We have found that the frequency distribution of SMAPI for 10 stations in China shows a Guassian distribution. We plan to continue this analysis using the multi-category approach, including both available soil moisture observations and model results over the Prairies.

<u>Real-time drought monitoring and forecast on the Web</u>

The reconstructed daily soil moisture over the Prairies described above is publicly accessible on line at http://www.meteo.mcgill.ca/~leiwen/vic/prairies/ This site also provides real-time drought monitoring and forecast of the Prairies soil moisture. This is done by one-way coupling VIC to the Canadian operational forecast GEM model, where GEM's daily precipitation and temperature forecasts are used to drive VIC. This provides real time updates of SMAPI fields every 24 hours with a lead time up to 4 days.

As an example, we show in Figure 2 the daily SMAPI for the three VIC soil layers on April 20, 2002 for the Prairies, together with the April average (bottom right panel) of the top 1 m layer. A field photograph taken is also shown as an inset in the figure, taken on the same day. There was a large-scale drought in the area between Saskatoon and Prince Albert on April 20, 2002. Quantitatively, our simulated SMAPI over the three soil layers characterized the drought as severe (-50% < SMAPI < -30%) to extreme (SMAPI < -50%). Indeed, most of the southern Prairie regions experienced severe droughts at the time.

We are in the process of further analysing the VIC-simulated soil moisture values for past drought events, including the recent drought of 1999-2005. This data set is available for use by DRI researchers.

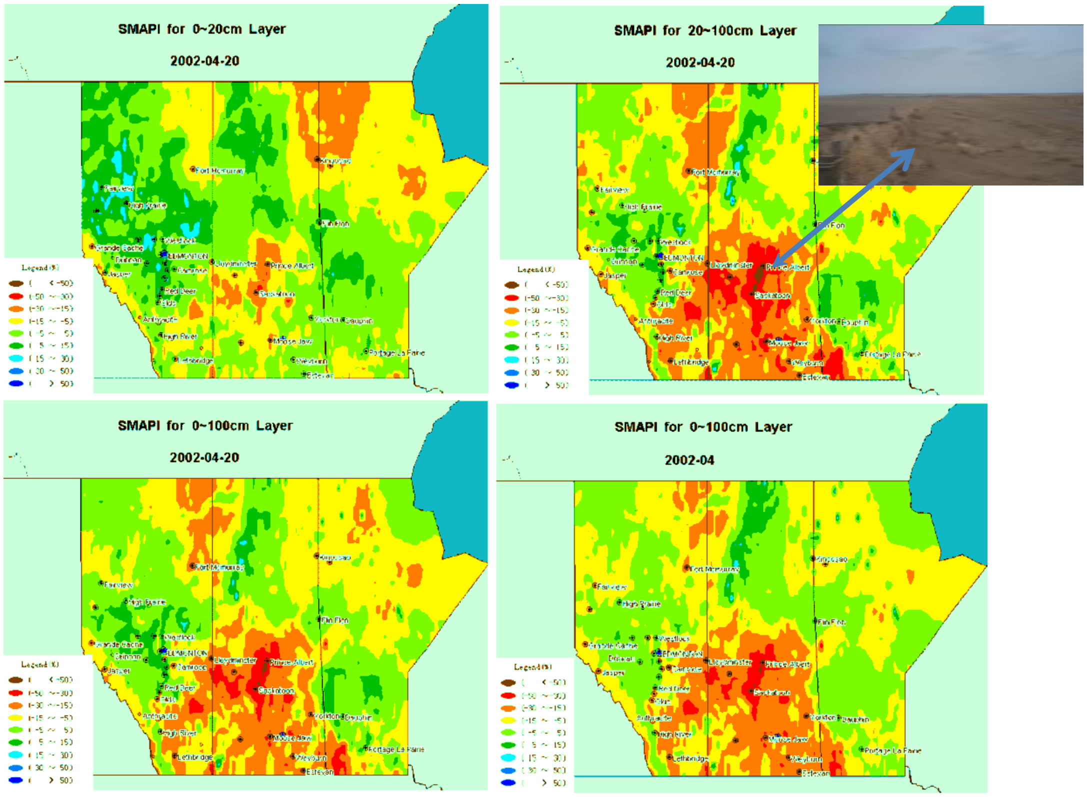


Figure 2: The VIC simulated SMAPI (Soil Moisture Anomaly Percentage Index) distribution of three soil layers (0-20 cm, 20-100 cm, and 0-100 cm) for the Prairies for April 20, 2002, together with the monthly April 2002 average (bottom right panel). A field photograph taken on the same day is shown as an inset in one of the panels.

<u>Skill of monthly and seasonal forecast using GCM3</u>

We examine the seasonal forecasts from the Historical Forecast Project (HFP) over North America; HFP is a CLIVAR project and is led by Jacques Derome of McGill University and George Boer of CCCma. This study is the M.Sc. thesis of Rabah Aider, supervised by Derome and Lin. The thesis examines the co-variability of surface air temperature (SST) and precipitation over North America, and Pacific sea surface temperature, using a singular vector decomposition (SVD) analysis. The leading SVD mode shows a strong link between November SST anomalies and winter surface air temperature (SAT) and precipitation anomalies. In summer, this relationship is much weaker. GCM3 captures well the Pacific SST forcing and its response, particularly on the SAT pattern, but less well for summer. The monthly and seasonal GCM3 forecasts show good predictive skill for 500 hPa heights and SAT, with higher scores in winter. The skill is concentrated in the first month of the prediction period and decreases as the lead time is extended to one month. Precipitation forecasts show little skill, especially in the warm season when the SST forcing is weak. GCM3 shows low skill in the seasonal forecast of drought events over the Canadian Prairies. In the HFP experiments, the SST anomalies are the main lower boundary forcing, with the soil moisture being initialised using climatological values. Using more accurate soil moisture information in the initial conditions could lead to improvement in the forecast skill, although this information may only be useful in limited regions

Analysis of soil moisture and groundwater using CLASS and gCLASS

Recall both GCM3 and CRCM have CLASS as their land surface scheme. Our analysis of GCM3 seasonal forecasts shows there is little skill in forecast of precipitation and drought events. Better initialization of soil moisture could contribute to the seasonal predictability. However, there is little direct observation of soil moisture available and model initialization thus remains a challenge. One way to get an estimate of soil moisture values is to use a hydrological model driven by observations, much as we have done with VIC. We thus use a similar approach with CLASS. The calibration and validation experience gained through VIC will prove useful, but CLASS requires more surface fields compared to VIC. We have made progress toward this end by preparing CLASS over a western Canada domain with 100 x 90 grid points that includes the Prairies. The domain projection is polar stereographic, with a nominal horizontal resolution of 51 km at 60°N latitude. The simulation period is from 1997 through 2007. We have prepared the necessary CLASS soil and vegetation parameter fields for each of the 4,759 land points in the simulation domain, and the corresponding meteorological forcing data sets for these points will be produced shortly. This work is done as part of the CFCAS-funded grant to PI Aaron Berg of Guelph University; Lin is a co-PI. The use of both VIC and CLASS for soil moisture analysis will permit model inter-comparison to identify strengths and weaknesses in each model.

The second activity focuses on gCLASS, a groundwater version of CLASS developed by Alan Woodbury's group at the University of Manitoba. We have successfully recompiled on a McGill University computer the main program of gCLASS and its associated library, provided by Woodbury's group. We have also reproduced the two results of benchmark runs. gCLASS will be run in a stand-alone mode to examine the coupling between the surface soil layers and the groundwater component over the Assiniboine Delta Acquifer.

Significant work is required in the preparation of CLASS fields that are needed for the CLASS and gCLASS experiments. Figure 3 shows two examples of necessary CLASS fields, the fraction of needle leaf tree coverage and the soil sand content index.

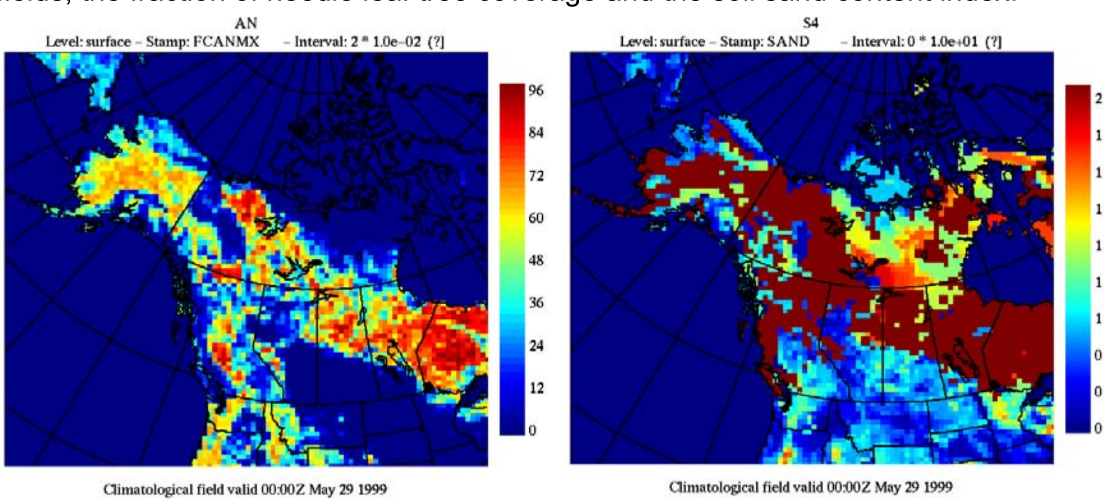


Figure 3: Two CLASS parameter fields: the fraction of needleleaf tree coverage and the soil sand content index.

Publications

1. Guihua Lu, Zhiyong Wu, Lei Wen, Charles A. Lin, Jianyun Zhang, Yang Yang, 2008: Real-time flood forecast and flood alert map over the Huaihe River Basin in China using a coupled hydro-meteorological modeling system. *Science in China Series E: Technological Sciences*, doi:10.1007/s11431-008-0093-x.
2. Lei Wen, Charles A. Lin, Zhiyong Wu, Guihua Lu, John Pomeroy: Reconstructing fifty-six year (1950-2005) daily soil moisture over the Canadian Prairies using the Variable Infiltration Capacity model. (To be submitted in early 2009)
3. Slavko Vasic, Charles A. Lin and Isztar Zawadzki: Comparison of precipitation from numerical weather prediction models and radars using a multi-category approach. (To be submitted in early 2009)

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

There has little analysis of the skill of seasonal forecast of drought by the Canadian operational or research models. Our project represents a first step in this direction. We plan to continue our work on soil moisture analysis using VIC, CLASS and gCLASS, and to investigate the idea that soil moisture initialization might increase seasonal predictability.

2.2 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.**

As explained above, our project has involved significant collaboration and networking with researchers within DRI and external to DRI. Our soil moisture analysis and groundwater work could lead to improvements in the treatment of land surface processes in seasonal forecast models. We are in close touch with Environment Canada in this aspect. We have made available on the DRI web site a link to our 56-year (1950-2005) daily soil moisture data set, and further collaboration with DRI researchers may result. Finally, M.Sc. student Rabah Aider has worked with DRI data managers Phillip Harder and Patrice Constanza to make available seasonal forecast data for the DEWS (Drought Early Warning System) component of DRI.

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.

Research results are published in refereed journals as they become available.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

As mentioned earlier, some of the model and reanalysis data are already available through the Data Access Interface. Additional data will be requested and made available for DRI members as research progresses. The 56-year (1950-2005) daily soil moisture over the Prairies from VIC is also available through the DRI web site.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

None.

Al Pietroniro

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title:

Investigator: Al Pietroniro

1.0 Progress (beginning January 2008 to end December 2008)

1.1. Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

Theme 1: Quantify the physical features of this recent drought:

Acquisition of data:

Brenda Toth (HAL) continues to provide support on data activities for DRI. Most of the datasets required for DRI have been made available on the web.

Current datasets are available on the DRI website (http://www.drinetwork.ca/data.php). Additionally a previous CCIAD-funded study on water availability in the South Saskatchewan River Basin (SSRB) generated significant data sets. A legacy data set, primarily physiographic data, has been archived. This was highlighted last year and the current status is that we respond to queries or updates.

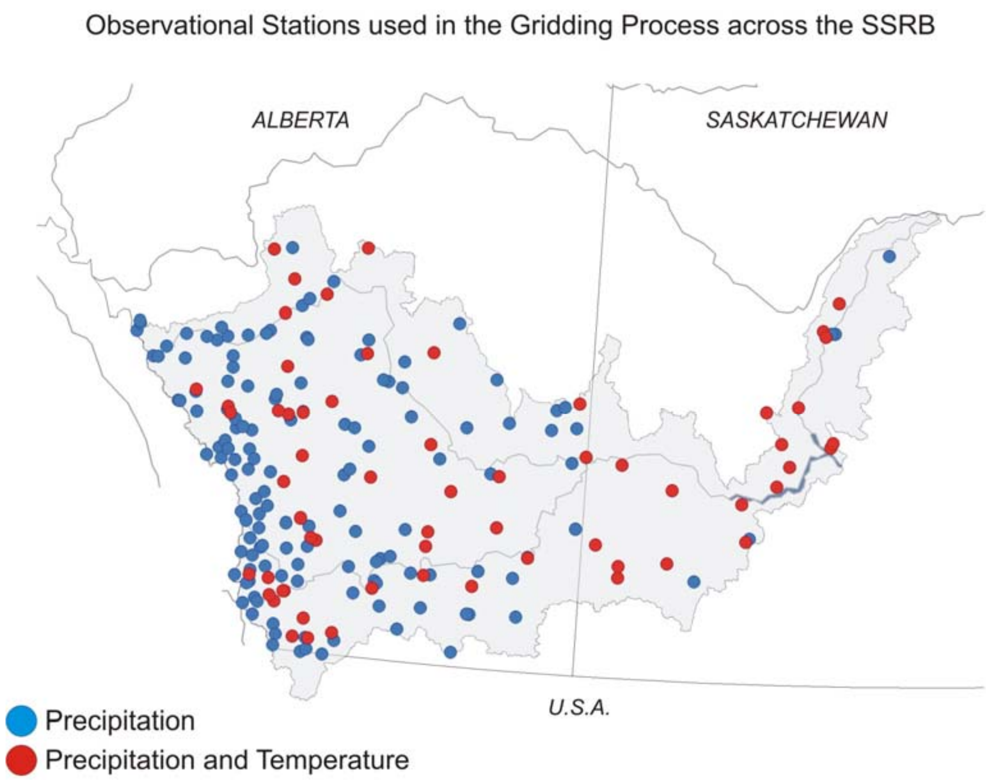


Figure 1. Climate stations utilized in the 1990 – 2005 gridding process. Note the temperature stations represent complete records, while the precipitation gridding canvasses shorter term records.

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

Continuation of enhanced observations of atmospheric, surface and groundwater processes in research sites, data acquisition from collaborating agencies, data rescue from previous observations, selection of numerical models.

Project 4. Land Surface Hydrology and Streamflow Processes *(Pomeroy, Granger, Papakyriakou, Pietroniro)*. This project is developing understanding of the primary physical surface processes underpinning Canadian Prairie drought, their sensitivity to land use, spatial scale and atmospheric conditions.

PhD work undertaken by Dean Shaw in the area of variable contribution area is supported by extensive field work in the St. Denis area, a hummocky terrain characterized by potholes that episodically contribute to stream flow. The field study included:

- Measured wetland water levels on a small-scale prairie basin, (spring 2002-2005).
- Measured groundwater levels on a small-scale prairie basin through peizometer readings, (spring 2002-2005).
- Snow surveys on a small scale-prairie basin (spring 2002-2005).

The field measurements taken during 2002-2005 have been used to quantify runoff volumes. Surface runoff during the spring melt is influenced largely by infiltration (Gray, et al., 2001). Using snow survey data as an input to a small-scale hydrological model, Shaw shows infiltration rates can be manipulated to satisfactorily model measured wetland water levels. Dean Shaw has 3 publications now completed and will be presenting at the DRI meeting in January. These publications are co-authored with Lawrence Martz. Thesis completion and defence is anticipated this spring.

A separate initiative is funded by the NAESI (National Agri-Environmental Standards Initiative) Water Availability project. A SWE/soil moisture mesoscale observation network is in the process of being established and the collected data will also be used to support the calibration and validation of the modelling efforts within the DRI project. The fieldwork is conducted in the Saskatchewan portion of the SSRB watershed.

- A network of 10 soil moisture stations have been installed in various crop types in the fall of 2006 and 14 additional stations were installed in the spring of 2007. These stations were coupled with rain gauges. These data are continually being
- Bi-weekly surveys of snow depth and density were completed for 2006/07/08 along 13 established transects in various crop types were completed. Scaled back surveys will be carried out in spring of 2009.
- A complete energy flux/ meteorological tower, which was be co-located with the mesonet in the spring of 2007. These data are now available and have continued through the summer of 2008.
- A deep observation well (geological weighing lysimeter) was installed within the mesonet in the spring of 2007 to measure regional soil moisture values. These data along with other lysemeter and deep well information have been collated and were continued for 2008.
- A data report is was completed last year for NAESI and is available to all DRI investigators. Date for 2008 is being compiled and likewise will be made available.

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

Given that the 1999-2004 drought and its features have been quantified and the fundamental responsible processes better understood, the next issue is to assess and improve predictive techniques. The modelling tools used are being developed into community-based models becoming accessible to a variety of researchers across the country. WATFLOOD, WATCLASS and CLASS are being combined to create MEC (Modélisation Environnementale Communautaire), along with a surface hydrology component (MESH). These community models are developed in conjunction with RPN in Dorval. The hydrological models are driven by output from the atmospheric models, ongoing research sites and available reanalysis data. Atmospheric modelling spans scales from global to regional to watershed scales characteristic of the prairies, while hydrological modelling is accomplished using a hierarchy from small scale detailed process models to large scale models run on the South Saskatchewan.

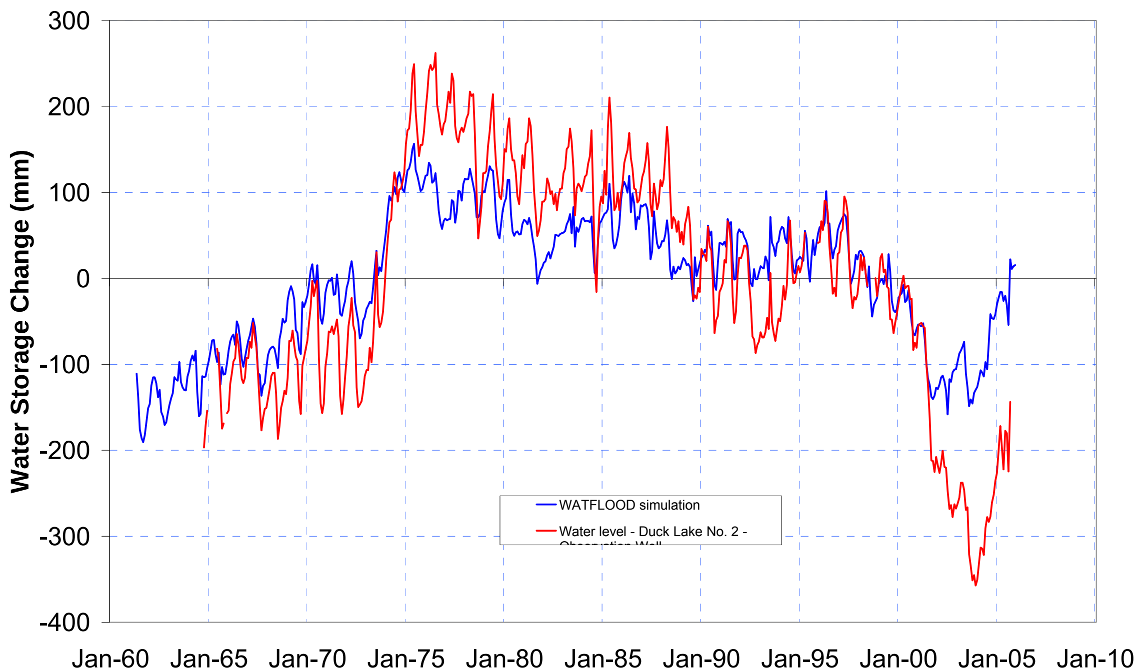
Project 3: Hydrological Modelling. This project is simulating the hydrology of large basins using a MESH prototype at a resolution of 15 km and smaller basins with CRHM at a resolution of 1 km. Full process model runs with enhanced soil, groundwater, ET and snow routines will be used to predict small scale runoff, soil moisture, ET and water balance without calibration of parameters. Large scale prediction using the MESH prototype model is being driven using atmospheric model output at the appropriate scale to generate South Saskatchewan River Basin flows from medium to large scales over hourly to seasonal time scales. Improvements to MESH will be made based upon new coupled modelling with groundwater simulations and results of CRHM simulations.

Characterization of surface water flow regimes and hydrologically significant variables, large scale modelling in the SSRB:
The gridded temperatures and precipitation as well as the physiographic datasets (see Theme 1) are utilized as inputs to the hydrological model WATFLOOD to estimate daily naturalized streamflow for 1990 – 2005 at 13 nodes across the SSRB. The current resolution is approximately 15 km by 15 km on an hourly time scale. Additional output (hourly AET, soil moisture, SWE) is available and is being examined and evaluated. WATFLOOD is the initial modelling framework; future modelling efforts will be accomplished with the MESH prototype. This modelling effort is undertaken by PDF Saul Marin. Unfortunately, this past summer Dr. Marin accepted a position in the private sector and this work was stopped. A suitable candidate could not be found. None-the less, it was possible to make improvements to the hydrological model and make long-term simulations with WATFLOOD, focusing on storage terms and comparing the results with the deep-well lysimeter work being carried out by Garth van der Kamp. A recent publication has been completed and is being submitted to the Journal of Hydrology. Comparison of long-term groundwater and recharge rates in the SSRB against the MESH modelling system were undertaken. In this case comparison of water balance components were examined, in particular the role of groundwater. The comparison measured groundwater storage to modelling of lower zone storage uncovered significant findings applicable to the understanding of the development of drought and our ability to model long term groundwater variability.

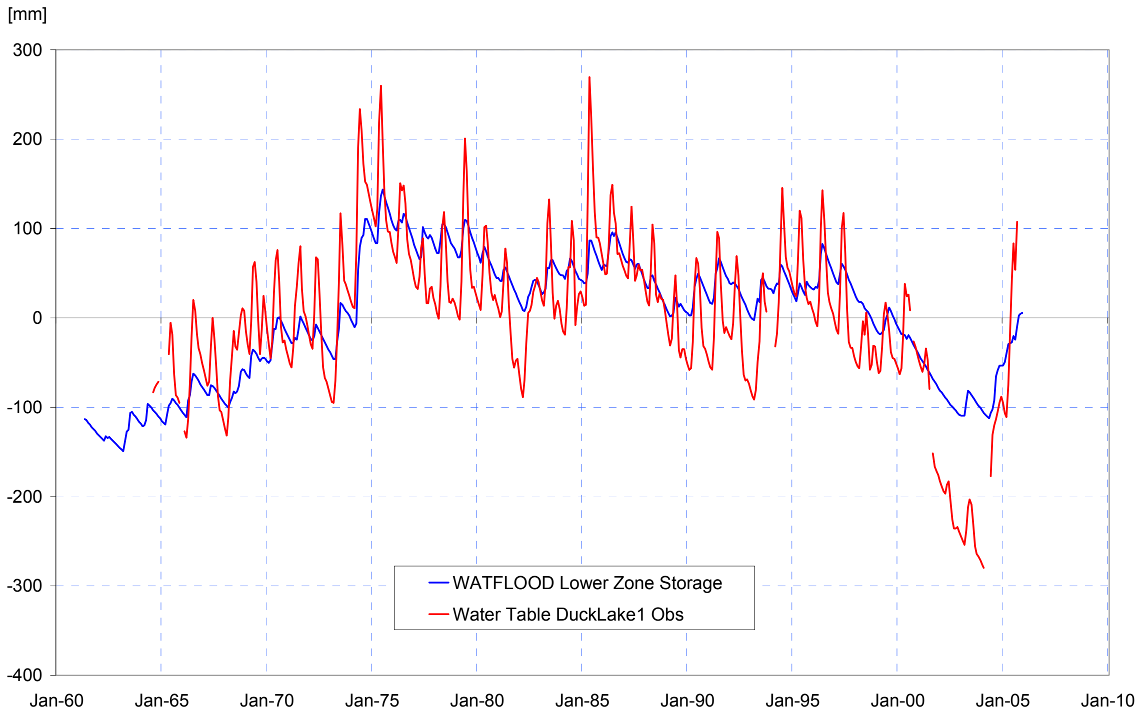
Long-term (30 year) records of deep observation wells in Saskatchewan, Canada, exhibit a clear relationship to changes of total vertical water balance at time scales from hours to years. Comparison of the well records and WATFLOOD ground water level outputs are done focusing in two times scales, monthly time scale in a period of 30 years (1961 – 1990) and hourly time in a three-month period (Jun 2003 – Aug 2003).

Monthly time scale results showed that the model has a good performance with the seasonal variability but it seems that there is a weak related to the low frequency variability (hydrologic long memory) shows the WATFLOOD groundwater level output and the observed level at the DuckLake2. The model misses the large change present around 1973-1975 and the long trend showed after 1976. Factors such as the record high snow year of 1973/74 and the possibility of external issues such as pumping for a high irrigation periods, changes in the way to measure the data may have influenced the well level data.

Simulation of vertical water balance: Duck Lake No. 2 record and WATFLOOD simulation (LZS + UZS + SWE).



Changes of groundwater storage: observed changes of water table storage (Duck Lake No. 1) compared with WATFLOOD simulation of lower zone storage (LZS).



Estimates of glacier contribution to flow within the South Saskatchewan basin have been completed. Two journals in preparation looking at historic contributions and changes in areal extent of glaciers within the SSRB are nearing completion. This work will contribute directly to DRI, but was funded through other initiatives. A rcent paper for the HP issue resulting from presentations at the CGU in 2008 has been submitted an review by L. Comeau. Average annual wastage and contribution to steramflow are estimated below.

Average annual glacier wastage and percentage contribution to streamflow for headwater basins in the N and SSRB is shown below.

Area	Gauge ID No.	Glacier Cover (%)	Flow Data Time Period	Average Annual Wastage (km³ water equivalent)	Percentage contribution to streamflow

					July-Sept	Annual
North Saskatchewan River Basin (not including Brazeau)						
Upper North Sask	05DA006	18.9	No data	98	*No Data*	*No Data*
Cline River	05DA004	2.7	No Data	16	*No Data*	*No Data*
Siffleur River	05DA002	4.1	1975-1996	15	10.9	*No Data*
Mistaya River	05DA007	12.1	1975-1998	16	13.2	7.8
Clearwater River	05DB003	1.0	1975-1992	8.4	4.5	*No Data*
Peyto Creek	05DA008	57.7	1967-1977	7.6	21.7	*No Data*
Central North Sask	05DA009	15.0	1975-1998	124	12.0	7.3
Ram River	05DC008	0.2	1975-1998	3.0	1.6	0.6
Lower Mistaya	05DA005	10.8	No Data	17	*No Data*	*No Data*
White Rabbit Creek	05DA001	1.7	No Data	3.9	*No Data*	*No Data*
Lower North Sask	05DA003	12.1	No Data	140	*No Data*	*No Data*
Silverhorn Creek	05DA010	3.3	1975-1998	0.3	4.2	2.2
South Saskatchewan River Basin (not including Oldman)						
Bow River	05BB001	2.8	1975-1998	26	4.8	2.2
Bow Lake Louise	05BA001	8.4	1975-1998	14	8.7	4.2
Red Deer River	05CA009	1.1	1975-1998	25	8.6	3.7
Kananaskis River	05BF023	2.4	No data	12	*No Data*	*No Data*
Pipestone River	05BA002	3.3	1975-1998	8.1	10.5	4.3
Spray River	05BC001	1.0	1975-1998	4.2	12.5	4.4
Redearth Creek	05BB005	2.3	1975-1996	1.4	3.3	*No Data*

Cascade R. Lake Minnewanka	05BD005	0.3	1975-1996	1.1	1.7	*No Data*
Highwood River	05BL019	0.1	1975-1998	1.1	1.4	*No Data*
Baker Creek	05BA007	0.8	1973-1976	0.67	2.0	*No Data*
Brewster Creek	05BB004	0.7	1975-1996	0.54	3.7	*No Data*
Johnston Creek	05BA006	0.4	1975-1996	3.4	1.4	*No Data*
Elbow River	05BJ006	0.1	1975-1995	0.11	0.2	0.1
Ghost River	05BG002	0.02	1975-1993	0.033	0.1	*No Data*

Small scale hydrologic modelling – process algorithm for depression storage:

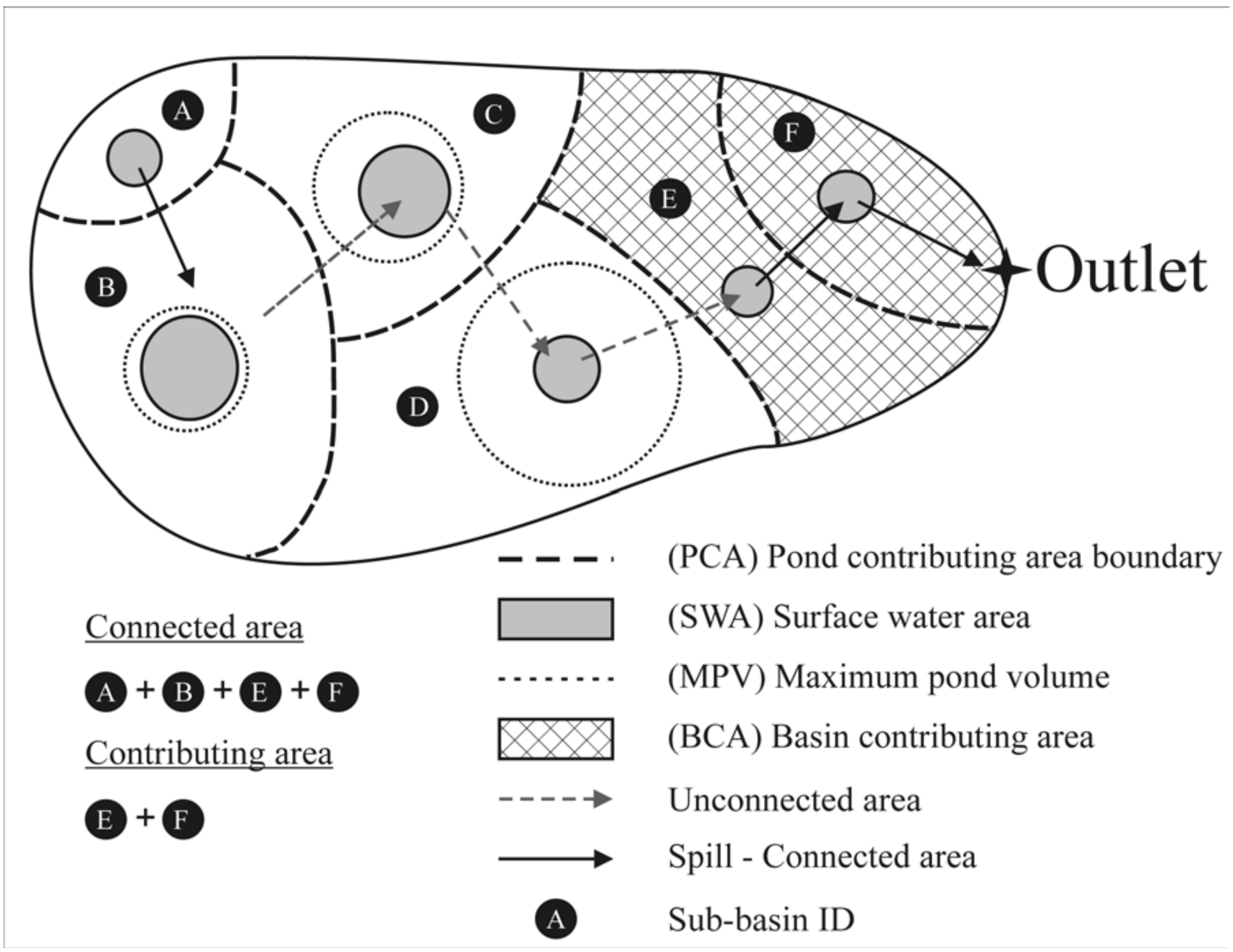
Within the current modelling framework, the area of the SSRB that is currently deemed to contribute to flow is the planar area less the PFRA estimation of the non-contributing area; however it is recognized that the non-contributing areas may episodically contribute to flow. This underscores the need to quantify depressional storage, identified as a key issue for Theme

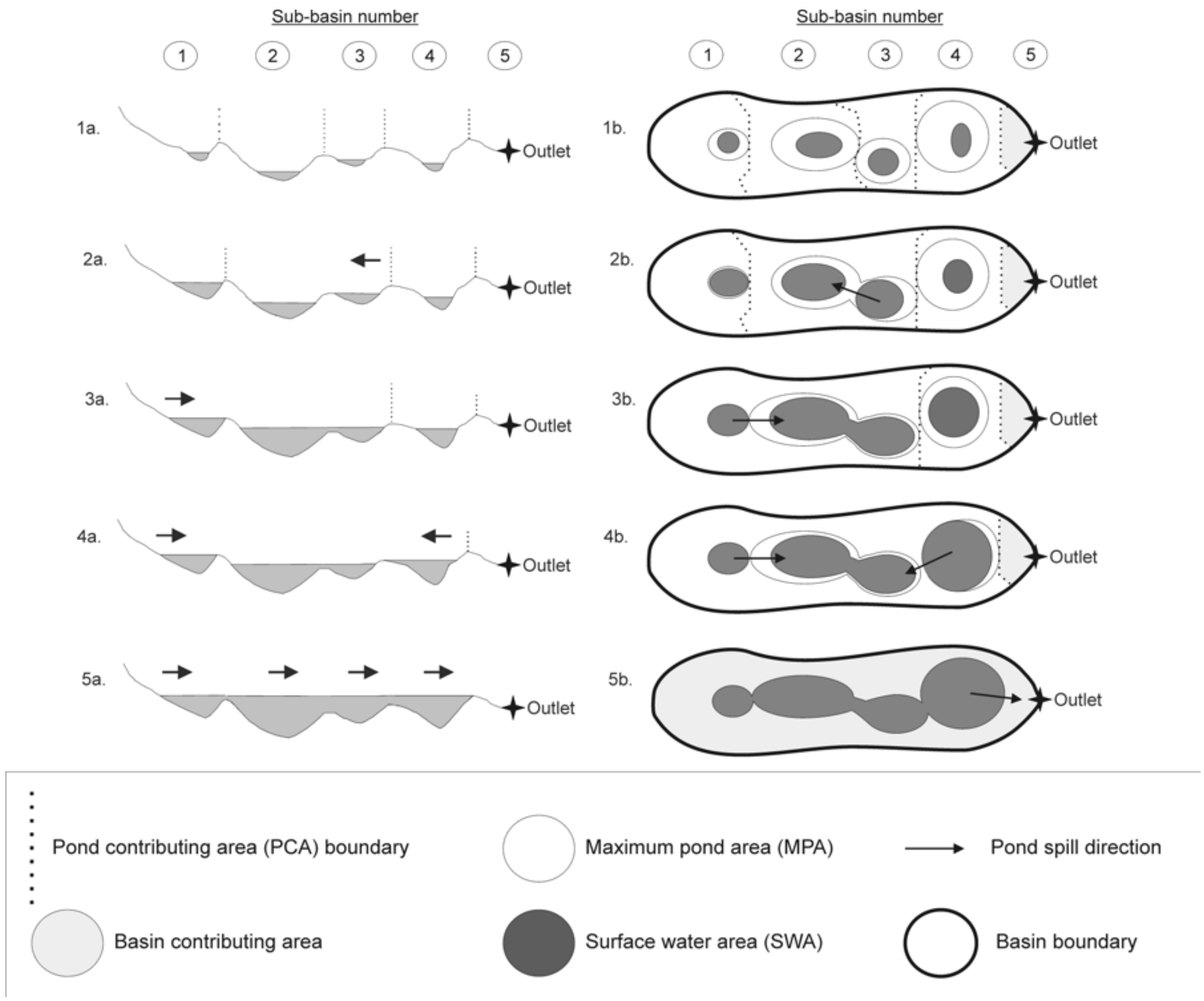
1. PhD work by DRI-supported student, Dean Shaw (see Theme 2) is directly applicable to a better parameterization of the area contributing to flow.

The analysis of the variable contribution area was conducted by examining the effect of infiltration on spring-melt surface runoff (using variable infiltration rates) for a small-scale prairie basin using input snow water equivalent (SWE) values from snow surveys and validated using wetland water levels.

Initially the effect of depression storage on the timing and magnitude of flood events was examined using a small-scale hydrological model - based on TOpographic PArameteriZation software (TOPAZ). Modelling the ‘fill and spill’ of depressions (wetlands) in the landscape, using current methods, has produced results that illustrate issues that arise using existing methods to determine how wetlands ‘fill and spill’. Efforts at scaling these algorithms to deal with variable contributing areas in the prairie pothole regions that dominate much the Western Canadian prairie are underway.

The research presented has shown that surface water connectivity between potholes in a prairie pothole basin has a tremendous influence on the extent of Basin Contributing Area and the resulting runoff volumes. Examination of historical pond levels at the St. Denis site has shown varied runoff volumes at the outlet of a basin in response to runoff events of similar magnitude. We have proposed the varied runoff volumes are the result of connectivity between potholes through surface water as potholes fill-and-spill. The PIT algorithm developed in a GIS environment has provided a methodology for defining the relationship between BCA and Surface Water Area SWA for pre-threshold storage runoff events. This relationship allows water resource managers and hydrological modelers to determine the state of connectivity in the basin using remotely sensed data such as air photos or satellite images to determine SWA in the landscape. The state of the basin connectivity is important for modeling runoff volumes at the outlet in a prairie pothole basin as connectivity has a tremendous impact on BCA and runoff volumes. A conceptual description of this phenomenon is shown in the 2 figures below.





There are two major ponds in the St. Denis basin; pond 1 (p1) which is located approximately in the middle of the basin and pond 90 (p90) situated downstream at the outlet of the basin (Figure 4). MPVs have been estimated for both potholes from the Lidar DEM of the region. P1 has been estimated to have a MPV of 20,000,000m^3 and p90 has been estimated at 90,000,000m^3.

Pond levels for p1 and p90 are below. The data shows a striking increase in pond levels in p90 in 2006 and 2007. In the spring of 2007, p90 is approximately 3m deeper than any other time in the last 39 years. The dramatic increase in pond level in p90 occurs over a very short time. During the fall of 2004 the basin was very dry and the antecedent conditions reflected the drought conditions that had persisted in the area since 1999 (Bonsal and Wheaton, 2005).

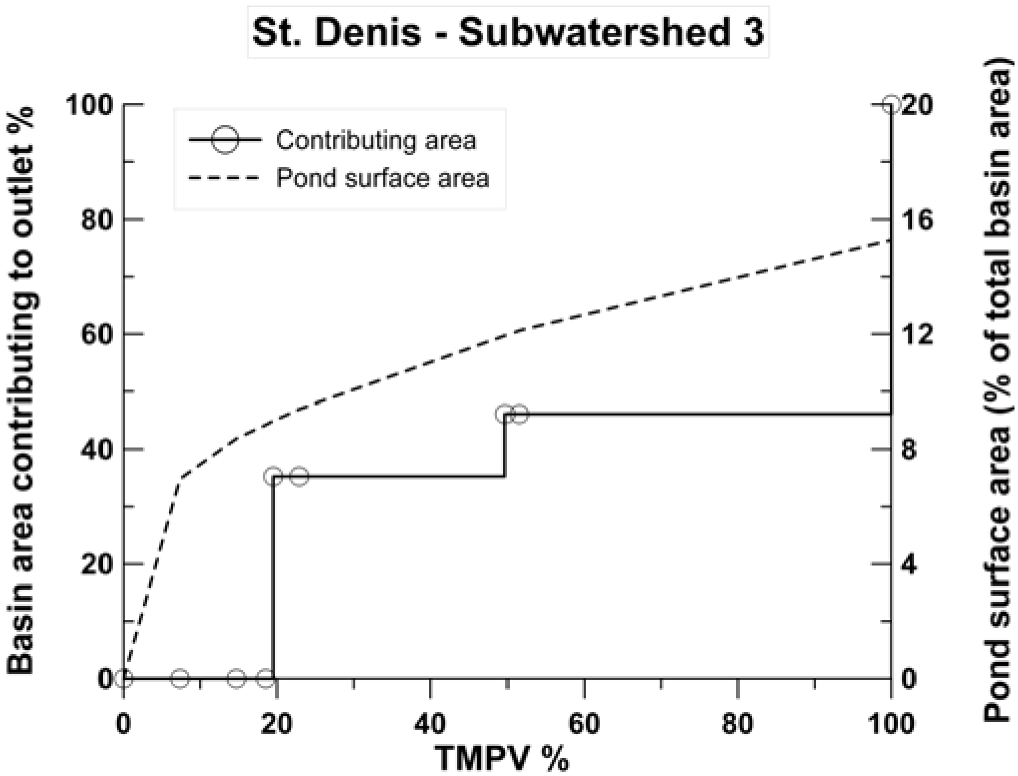
P90 was completely dry in the fall of 2004 and p1has the lowest recorded depth since 1968.

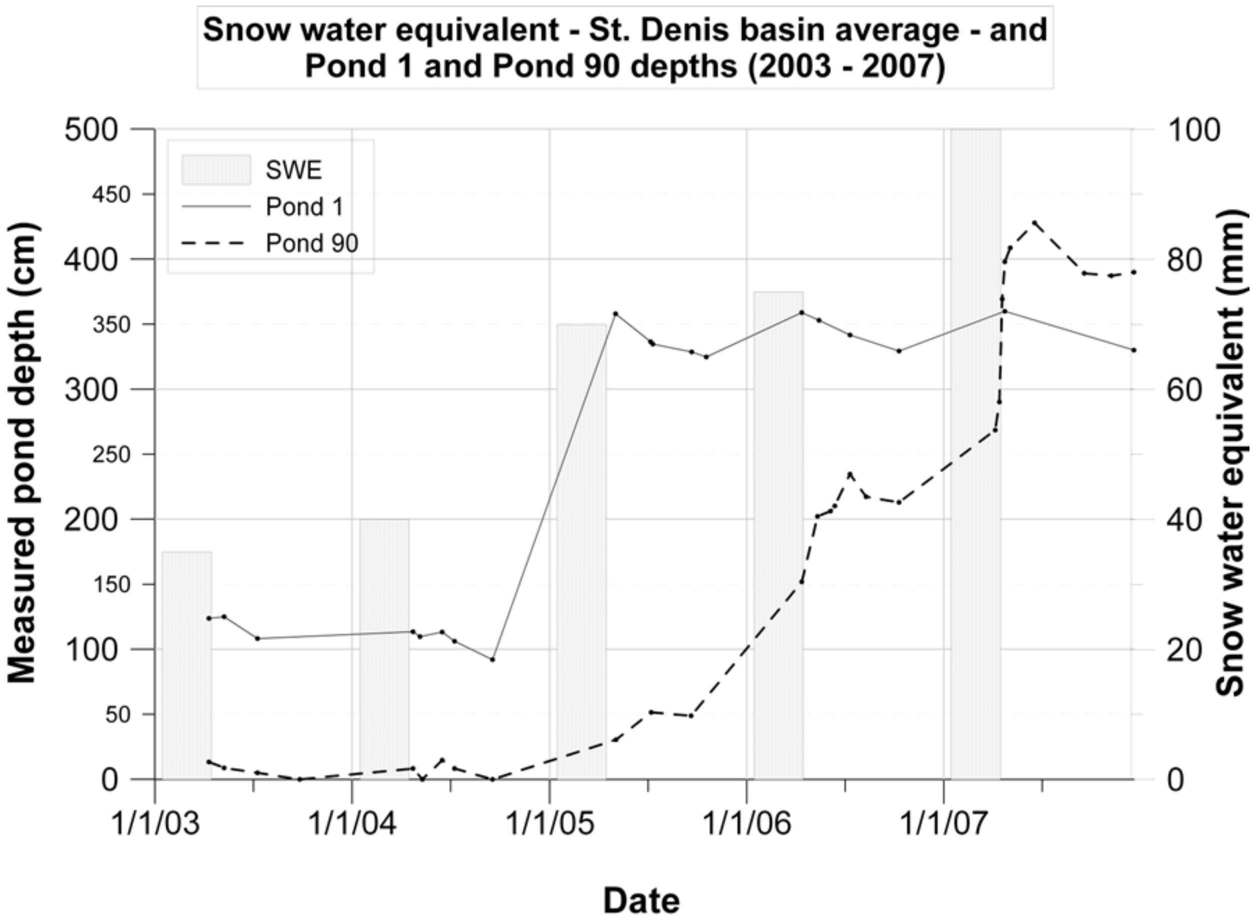
The figure illustrates the pond level increases for p1 and p90 for the 2005 spring runoff event. What is interesting is pond depth increases for p1 and p90 are dramatically different. The pond level in p1 has increased over 2.5m to a depth of 3.51m. This is the depth at which p1is full and spills downstream. However, in response to the same runoff event p90 increases by only 0.25m. During the spring of 2006 snow water equivalent (SWE) values measured in the basin were very similar to measured values in the spring of 2005. However the response of the basins to similar SWE conditions differed dramatically between the two years. Because p1 remained very close to full in the fall of 2005, very little runoff was required to raise the pond level in the basin to the spill point. As a result, connected area contributing to p90 dramatically increased very early in the 2006 spring melt runoff event and pond level of p90 increased 1.5m. This increase is 6 times the pond level increase of 2005 although SWE available for runoff for both years is comparable.

The spring snowmelt runoff event in 2007 again saw a dramatic rise in pond depth level in p90. As in 2006, p1 has filled and spilled early in the runoff event allowing the entire basin to connect to p90. This results in another 2.2m of pond depth added to p90. The increase in pond level is 0.7 m greater than in 2006. The increase may be attributed to 20% more SWE available for runoff in the spring of 2007 (Figure 6c).

What the response of p90 illustrates is the importance of connected areas in modeling the hydrology of the prairie pothole region. The fill-and-spill of potholes influences the extent of connected area and can influence the BCA. What the pond level data at St. Denis reveals is that basin storage can be satisfied in such a manner that minor runoff events, can cause a tremendous increase in BCA. Water resource managers in the prairie pothole region would benefit greatly from an algorithm that determines the state of basin storage and how close the basin is to being connected in a manner that dramatically increases BCA.

A relationship (see figure below) between contributing area, surface water extent and total basin storage incorporating the “fill and spill” understanding to ensure a true representation of this hydraulic phenomenon was developed and compared to the observed values shown.


St. Denis - Subwatershed 3
Contributing area
Pond surface area
Basin area contributing to outlet %
Pond surface area (% of total basin area)
TMPV %
0
20
40
60
80
100
0
4
8
12
16
20



Results from this work are are being summarized in a series of 3 papers and will contribute directly to the students thesis.

1.2 **Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.**

A number of projects have been completed and we envision a few main outcomes in the next year and a half. The fill and spill, glacier and lysimeter work have all contributed to increased understanding and conceptualization of hydrological parameterization within the SSRB domain.

Total journal publications for this work are estimated as 4. (Shaw – 2, Comeau – 1, Maurin, - 1)

Continuation with the MESH simulations at the Kenaston site will continue. Recent collaboration with the University for Calgary and the availability of a graduate student to assist with field, data and simulation aspects of this work will contribute to the overall results. The focus here will be on completing 3 years of simulation using MESH for the Kenaston mesonet site (as presented last year). The MESH domain is already established, and this will provide the student a unique opportunity to access the data collected at the site for the last 3 years. Project deliverables (data report, simulation results) will be completed by the Calgary student over the summer and fall of 2009) and will contribute directly DRI, while providing t he student with a data set and model for his continuing Ph.D. studies after the DRI deliverables are complete.

Incorporating these finding and re-analysis of flow estimates for 1960-present will be undertaken using MESH and should provide a final simulation of hydrological response in the region for that period. Using a simple change in temperature and precipitation approach, a climate change assessment will be re-evaluated within MESH as well.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

Theme 1 Deliverables:

- Collective dataset(s) archived on CDs characterizing the drought
- Outreach to DRI community and stakeholders through workshops and conferences

Deliverables Achieved:

- Datasets available on DRI website, through DRI Information Managers and SSRB legacy dataset CD
- Continued improvements and validation of the MESH modelling system

Theme 2 Deliverables:

- Improve the understanding of the large scale setting of drought
- Improve the understanding of surface-atmosphere feedbacks of energy and water
- Improve the understanding of ET at various scales from prairie land and water surfaces

Deliverables Achieved:

- A field study that examined the effect of infiltration on spring-melt surface runoff (using variable infiltration rates) for a small-scale prairie basin using input snow water equivalent (SWE) values from snow surveys and validated using wetland water levels

- Establishment of a SWE/soil moisture mesonet, co-located flux towers and a deep observation well.
- Data report to be complete by the end of 2008 includes all soil moisture, flux and SWE data collected in 2007 and 2008.

Theme 3 Deliverables:

- Improvements to the land-surface scheme CLASS, used within the MESH prototype, from appropriate inclusion of groundwater, frozen soil, ET, snow, contributing area change and other processes
- Assessment of drought characteristics simulated by CRCM
- Assessment of skill and uncertainty of seasonal forecast of drought indices
- Improvements to small-basin to field scale hydrological modelling capability for drought simulation
- Assessment of prairie basin runoff changes during development and termination of droughts

Deliverables Achieved:

- SSRB modelled at a 15 km resolution on an hourly basis with daily streamflow output
- Comparison of WATFLOOD modelled lower zone storage with observations show that yearly trends are well represented in WATFLOOD, however longer term trends may be missed as the model may not carry interannual additions to or depletions of groundwater. Also, at times the model may not be replicating evapotranspiration at the dry end as the modelled storage is depleted and the model deems that evapotranspiration has ceased. Improvements to model physics in replication of a variable lower zone storage is needed.
- Knowledge and quantification of contributing area change and an improved ‘fill and spill’ algorithm developed that explored the spatial pattern and distribution of wetlands under synthetic runoff events. This work is largely complete. Scaling methodology and completion of thesis and journal manuscripts are expected by April, 2008.
- CLASS code review of vertical fluxes (snowmelt infiltration) and sloped CLASS routing (overland flow, interflow and baseflow)
- MEC/MESH development and link to NWP through RPN in Dorval. We have made significant process in developing and using software engineering processes to improve our ability to collaborate with DRI network participants. First and foremost, we have successfully implemented an accessible software configuration management (SCM) system for effectively working with code developers and modellers across the country. The system revolves around a central repository of model code, documentation and run files that can be downloaded by anyone with a computer, internet access, username and password. The repository has three main directories: a trunk directory for the latest version of the model, a tag directory for tagged releases of the model, and a branch directory containing sub-directories for each developer or model user to do his or her work. The trunk and tag directories can only be altered by a very limited number of people. To date, successful training, implementation and use of the SCM system has been completed with individuals at the Hydrometeorology and Arctic Laboratory (HAL), Recherche Prévision Numérique (RPN), the University of Waterloo and the University of Saskatchewan. Other advances in the implementation of software engineering include improved documentation and the beginning of regular code reviews of MESH subroutines. We have also begun to organize monthly conference calls amongst model developers and users.

2.2 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);**
  - Linkages of NWP to MEC/MESH to aid in forecasting land surface variables
  - Underscored the need for the development of distributed data products

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**
  - Dr. Collins with the University of Calgary, remote sensing and satellite verification links to the NAESI field study.

- **Whether and how it has improved the reliability of predictive methods;**
  - CLASS and MEC/MESH code review and improvements, links to NWP through RPN

- **The impact of the project on your own institution;**
  - Synergy of activity in arid region research (i.e. DRI and NAESI)

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**
  - New partnerships with University of Calgary, increased involvement with RPN in Dorval

- **Any current (or potential) commercial or social applications, which the results may have;**
- **Links with international initiatives and the potential impact of these;**
  - This work was highlighted at GEO meetings and the MESH and Kenaston data are being highlighted as potential contributions to GEO initiatives.
  -
- **Anticipated benefits of the work for Canadians**
  - Improved understanding of water availability for the agricultural industry
  - Better understanding of cold regions hydrology; contributing area change, generation of spring runoff, SWE/soil moisture relationships

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Use of Observation Well Records for Confined Aquifers to Evaluate Modelling of Areal Evapotranspiration, Saul Marin, Garth van der Kamp , Alain Pietroniro, Bruce Davison and Brenda Toth. Submitted – Journal of Hydrology.

Topographic Analysis for the Prairie Pothole Region, Dean Shaw, L.W. Martz and Alain Pietroniro, Accept with revision – Hydrological Processes

The influence of surface water connectivity on runoff in a prairie pothole region, Dean Shaw, L.W. Martz and Alain Pietroniro, under review – Journal of Hydrology

Conference presentations:

Others:

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

All data is being archived and will be part of the HAL lab data collection. Data will be made available upon request.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

John Pomeroy

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title: Canadian Hydrological Drought Processes and Modelling

Investigator: John Pomeroy

1.0 Progress (beginning January 2008 to end December 2008)

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

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.

Evaporation during Drought

Developing techniques for characterizing evaporation during drought has been a major focus of research on Theme 1 as current modelling techniques for evaporation are felt to be inadequate to accurately describe the limited evaporation that occurs under severe drought conditions. A physically-based hydrological model that considers the interactions of infiltration, evaporation, and soil moisture accounting was assembled using existing modules within the Cold Regions Hydrologic Model (CRHM) platform. Actual evaporation was calculated over the summer period of 2001 at a short grass prairie site located at Lethbridge, Alta (AMERIFLUX) using a resistance-based model (Penman-Montieth) and a complementary feedback model (Granger-Gray). Both models extend the Penman potential evaporation model to the case of a non-saturated surface which has particular relevance during drought. Surface resistances in Penman-Monteith were increased using standard methods (Jarvis) as a function of soil moisture. Granger-Gray evaporation responds solely to atmospheric conditions. The results show that both the Penman-Montieth, and Granger and Gray models may produce large overestimates of evaporation during a drought period when allowed to run solely as atmospheric models. A coupled soil moisture-precipitation-runoff water balance approach was necessary to further limit evaporation during such periods of severe moisture stress. By restricting evaporation from these atmospheric evaporation models based on enforcement of soil moisture continuity from a hydrological water balance, good performance of both evaporation models could be obtained. Evaporation characterisation of drought will require rigorous coupling of existing atmospheric schemes to the soil hydrological system to provide realistic results.

Prairie Hydrology in Drought

The effects of drought on first order stream and internally drained wetland basins is being determined by evaluating the changes in several variables relative to their mean values during the normal period, hydrological response units (HRU) of i) a small virtual well drained basin with a stream, and ii) a small virtual internally drained basin with a wetland in gridded runs of CRHM (see Theme 3 report for explanation of predictive model). These variables include

1. SWE accumulation,
2. Soil moisture,
3. Spring freshet runoff,
4. Total annual discharge,
5. Evaporation/sublimation.

Work to Date

A stream basin model has been developed, and has been run for the 1961-1990 normal period for Winnipeg. As shown in **Error! No bookmark name given.**, the SWE computed for fallow fields varied tremendously from year to year. The mean SWE values, plotted in **Error! No bookmark name given.**, show the large reduction in SWE during the drought years, even at Winnipeg, which was less affected by the drought than regions further to the west. The calculations take significant quantities of CPU time. A 30-year run for a single model at a single location takes approximately 30 minutes to complete. Since several models will be run for each site, and many sites will be simulated, a calculation server PC has been setup to do the computations.

Meteorological variables required by CRHM have been obtained from a number of sources. The Data Access Initiative (DAI) of Ouranos has been able to provide hourly wind speed, temperature and relative humidity data. Unfortunately, the Ouranos hourly precipitation data is limited to rainfall and having both rainfall and snowfall are essential for hydrological modelling. This means we are extracting daily snowfall totals from the Environment Canada archive and interpolating these to hourly values. Because the measured snowfall data are known to be strongly affected by wind speed, these data are being corrected using Goodison’s adjustment for the Nipher wind shield, which is incorporated in CRHM. A positive feature is that the snowfall rate is far less important than is rainfall intensity, so that the effect of any errors in disaggregating daily snowfalls to hourly values will be small.

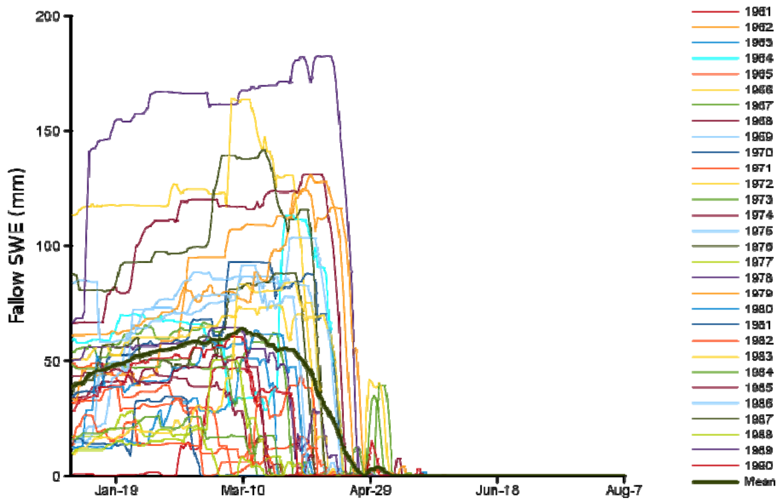


Figure 1: Simulated SWE(mm) for Fallow field at Winnipeg for climate normal period of 1961-1990.

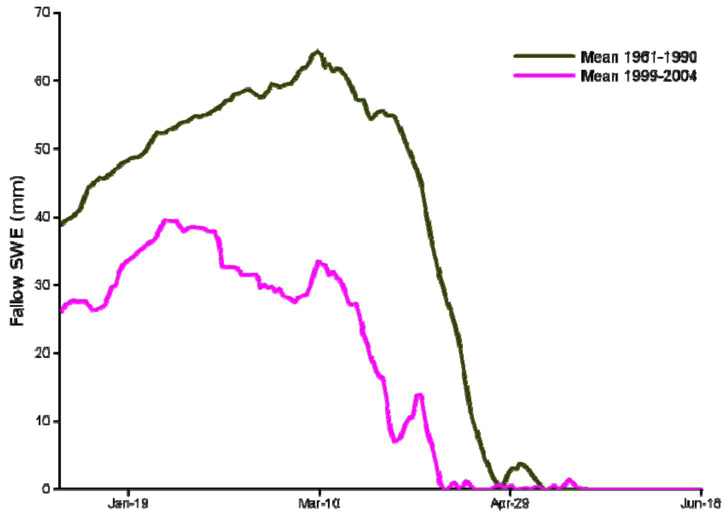


Figure 2: Mean fallow SWE during normal and drought periods.

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

Research continues towards improving our understanding of the spatial variability of evaporation at a Prairie location in central Saskatchewan. Theoretical developments have led to an introduction and practical demonstration focused on distributing evaporation estimates over the natural landscape at St. Denis NWA, Saskatchewan (Armstrong, Pomeroy, Martz, in preparation). The case study introduces the use of an index-based remote sensing approach to obtain distributed estimates of actual evaporation. The objective is to obtain distributed mean daily evaporation estimates from one-time-of-day (near solar noon) visible and thermal imagery and surface reference meteorological data. The major development of the method is that a single reference value of mean daily net radiation may be distributed over the landscape by indexing mid-day net radiation (partly parameterized from remote sensing imagery) based on known values obtained at a reference location. Therefore the index is used as a spatial and temporal transfer function from which net radiation may be distributed over larger regions. Estimates of daily net radiation are within approximately 5 – 10 % of measured values at two validation sites. The Granger and Gray evaporation model (G-D model) was then applied for demonstration purposes. An estimate of evaporation was found to be about 0.5 mm higher than that measured by the eddy covariance method. The technique may be readily applied using satellite remote sensing data and surface meteorological data. An advantage of the approach is that variations in actual land surface properties drive observed differences in surface reflected and emitted radiation components of the net radiation balance, and allow for daily evaporation to be estimated directly and realistically without need for soil moisture measurements. The model itself may find useful application for prairie hydrology or in relatively data sparse regions. Further, based on theoretical considerations of the model approach, it may be possible to provide valuable information as to spatial variations in evaporation and realistically infer relative differences in soil moisture over the landscape.

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

Although the climatological conditions which define a drought are generally well understood, it is more difficult to define hydrological drought. The hydrography of the Candian prairies is unlike that of most regions of the world. Being composed of very small streams and internally-draining basins, the prairie hydrography strongly influences the hydrological properties of this region, and therefore its response to drought. The response of first order prairie basins is generally unmeasured but critically important to understanding the impact of drought on prairie hydrology. The objective of this component is to determine the responses of typical first order prairie basins to the drought of 1999-2005, and the way in which these responses varied both temporally and spatially, by modelling their hydrological responses to drought and non-drought conditions. All simulations are being undertaken using the program CRHM, which has been shown to accurately reproduce prairie hydrological processes (Pomeroy et al., 2007; Fang and Pomeroy, 2008). The simulation consists of two model configurations, the first being that of a small well drained watershed containing a first order stream, the second consisting of a internally drained wetland and the adjacent land draining into it. Both are typical of prairie hydrography. The simulations are being carried out over two time periods: 1) the climate normal period of 1961-1990, and 2) the drought period of 1999-2005, allowing comparison of the basins' responses to "normal" and drought conditions.

Because the environmental conditions vary spatially, the virtual basins are being simulated at a number of locations throughout the prairies. The outputs of the models can, by spatial interpolation, be converted to surfaces over the prairies. CRHM's meteorological data requirements are fairly modest: air temperature, humidity, wind speed, precipitation, and solar radiation. Importantly, soil moisture is not necessary as an input variable but is tracked by the model as a state variable output. Unfortunately hourly values of meteorological data are required which, combined with the long periods of the model runs, require the use of very large quantities of data - over 324,000 values for each variable, for each location. Apart from being very difficult to manage, such large datasets require significant effort in QA/QC. Gridded environmental datasets are an obvious method for incorporating spatial variability in the simulations. Unfortunately, the gridded datasets currently available are either at too-large temporal scales, or are of poor quality (NARR, NCEP). The only alternative is to use data measured at meteorological stations, and to interpolate the simulation results. Solar radiation data are particularly problematic, as they have only been measured at a (very) few locations in western Canada. CRHM minimizes this problem to a certain extent, as it is able to synthesize the hourly components of the solar radiation balance, given values of QsiD, the daily incoming shortwave radiation. For the majority of sites, where measured values of QsiD are unavailable, synthetic QsiD values, determined from empirical equations or from reanalysis datasets, are being used.

The first order basin models are being run for the normal period, and for the drought period, using a water year extending from Oct. 1 to Sept. 30. At the beginning of each simulation year during the normal period, the soil moisture is reset to an average value to prevent systemic errors from accumulating during the 30-year run.

Stream model

The small stream model is based on models developed of the Creighton Tributary of Bad Lake Research Basin (Pomeroy et al., 2007) and tested using IHD archived datasets. Because the model emulates the behaviour of a particular stream and well drained basin, it is possible to check the model's behaviour against recorded data. CRHM is based on HRUs (hydrological response units) which are defined to describe the hydrological behaviour of major land units. The HRUs for the stream model correspond to fallow, stubble, grass and shrub vegetation. The fallow and stubble are located in the uplands, and the grass and shrubs are in the stream valley. Blowing snow moves moisture from the smoother elements to the rougher; gravity moves water downhill.

Wetlands model

The wetlands model is also based on a real location, the Smith Creek basin, which spans the Saskatchewan - Manitoba border. Supplementary funding to study Smith Creek is provided by the Prairie Habitat Joint Venture Committee, PPWB and PFRA. The model HRUs correspond to fallow and stubble fields, and to individual wetlands. As the volume of water stored in the wetlands changes, the individual ponds will connect and disconnect, changing the active area of the watershed.

1.7 **Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.**

The remote sensing evaporation estimation method will be used to examine variations in actual evaporation over the entire Canadian Prairie region during the drought period. MODIS data, Environment Canada and NARR will be integrated for the modelling process. The methodological approach for this was recently outlined at the Drought Characterization workshop in Winnipeg on Sept 26, 2008.

CRHM runs will be completed for grids covering the Prairie region to product first order basin hydrology. This hydrology will then be analysed to better describe the drought.

CRHM prairie hydrology model aspects will be used to advise the development of MESH for Prairie runs by the HAL laboratory.

2.0 <u>Impact</u>

2.1 What short and medium term objectives have been achieved, or are anticipated;

Better understanding of internally drained wetland runoff sensitivity to drought has been achieved. Characterisation of prairie wetland dynamics during drought cycling has been accomplished. A method to upscale evaporation rates from a point to a small grid cell using remote sensing has been developed and tested. CRHM has been adapted so that it can simulate the drought hydrology of both well drained and internally drained basins and data assembly for gridded CRHM drought runs is well under way.

2.2 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 streams and rivers. 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. CRHM is being used to study the effect of wetland drainage on inflows to the Upper Assiniboine watershed from Saskatchewan to Manitoba.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Armstrong, R.L., Pomeroy, J.W. and L.W. Martz. 2008. Evaluation of three evaporation estimation methods in a Canadian prairie landscape. *Hydrological Processes*, 22(15). 2801-2815. (refereed)

Fang, X. and J.W. Pomeroy. 2008. Drought impacts on Canadian prairie wetland snow hydrology. *Hydrological Processes*, 22(15). 2858-2873. (refereed)

MacDonald, J. and J.W. Pomeroy. 2008. Gauge undercatch of two common snowfall gauges in a prairie environment. *Proceedings of the Eastern Snow Conference*, 64. 119-126. (refereed).

Fang, X. and Pomeroy, J.W. Modelling blowing snow redistribution to prairie wetlands. Hydrological Processes: accepted.

Conference presentations:

Armstrong, R.N., Pomeroy, J.W., and Martz, L.W. 2008. Examining the spatial variability of actual evaporation under clear skies. CGU Annual Meeting, Banff, May, 2008.

Armstrong, R.N., Pomeroy, J.W., and Martz, L.W. 2008. Progress towards calculating actual evaporation over the Canadian Prairie region during drought. DRI Drought Characterization Workshop, Winnipeg, Sept, 2008.

Fang, X. and Pomeroy, J.W. 2008. Spatial Scale for Modelling Blowing Snow (Poster). Drought Research Initiative (DRI) Annual Workshop 3, Calgary, AB. January 17, 2008.

Pomeroy, J.W., Fang, X., Minke, A., Westbrook, C. and Guo, X. 2008. Prairie Wetland Hydrology Processes and Modelling. Prairie Habitat Joint Venture (PHJV) Science & Policy Forum 2008, Saskatoon, SK, April, 2008.

Pomeroy, JW, Prairie Water and Climate Change, Prairie Habitat Joint Venture Science and Policy Forum Banquet Speech, Saskatoon, April, 2008

Pomeroy, J.W. Snow Physics and Hydrology, Kirkham Conference, Univ of California, Davis Feb. 2008.

Pomeroy, J.W. Recent Advances in the DRI Study. Agriculture Canada GRIP Workshop, Saskatoon, March, 2008.

Pomeroy, J.W., Martz, L.W., Shook, K. Fang, X. and Armstrong, R. 2008. Canadian Drought Hydrology Processes and Modelling. DRI 3rd Annual Workshop, Calgary, Jan. 2008.

Pomeroy, J.W. 2008. Aspects of Prairie Hydrology. Saskatchewan Ministry of Agriculture, Water and Agriculture Workshop, Saskatoon, June 2008.

Shook, K. and J.W. Pomeroy, 2008 Evaluating gridded datasets for physically based hydrological modelling of drought. DRI Drought Characterization Workshop, Winnipeg. Sept. 2008.

Shook, K. and J.W. Pomeroy, 2008. Stationarity Analyses of Historical Canadian Prairie Hydrometeorological Data. CGU Annual Scientific Meeting, Banff, May 2008.

Shook, K. and J.W. Pomeroy, 2008. Short-term Temporal Stability of Canadian Prairie Hydrometeorological Data. American Geophysical Union, San Francisco, Dec 2008

Shook, K. 2008. Testing the stationarity of historical meteorological data on the Canadian prairies . Third Annual DRI Workshop, Calgary, Jan. 2008.

Others:

King, J.C., Pomeroy, J.W., Gray, D.M., Fierz, C., Föhn, P., Harding, R.J., Jordan, R.E., Martin, E. and C. Plüss. 2008. Snow-atmosphere energy and mass balance. In, (eds. R. Armstrong, E Brun) *Snow and Climate, Physical Processes, Surface Energy Exchange and Modelling*. Cambridge University Press, Cambridge, UK. 70-124. (reviewed)

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Data is being archived in the Centre for Hydrology central archives on a terabyte server. It is being made available to other researchers upon request.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

Canada AM Interview on Drought (April, 2008)

Star-Phoenix Op-Ed, June 2008 (water supply for export)

Ken Snelgrove

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title: ***<u>Soil Moisture Initialization for Numerical Weather Prediction</u>***

Investigator: Kenneth R. Snelgrove

1.0 <u>Progress (beginning January 2008 to end December 2008)</u>

1.2 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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

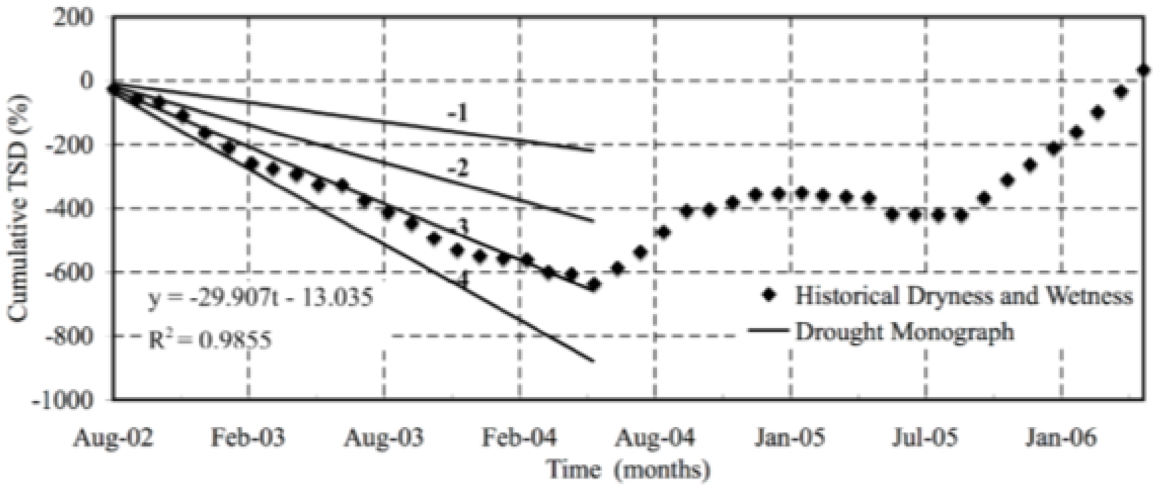
The overall objective of the Drought Network Initiative (DRI) is *to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that began in* 1999.

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

Theme 1: Quantify the physical features of this recent drought:
b) 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.

i) ***GRACE Storage Measurement***: The remote sensing observations of gravity from the GRACE satellite system can be translated into monthly measurements of land surface moisture stored within the Saskatchewan River Basin. This work has continued in 2007-2008 with the development of a methodology for drought index assessment directly from satellite observation. The method fellows the general approach of the Palmer Drought Severity Index (PDSI) but uses only gravity observations from satellite to determine the index. The plot below shows the cumulative total storage deficit (TSD) as derived from the GRACE satellite plotted for the Saskatchewan River basin as a whole. The period from August 2002 to May 2004 corresponds to a PDSI value of -3 (severe). These results would be useful in determining regional responses to drought that may be difficult to assess otherwise because of the nonlinearities in the averaging station data.

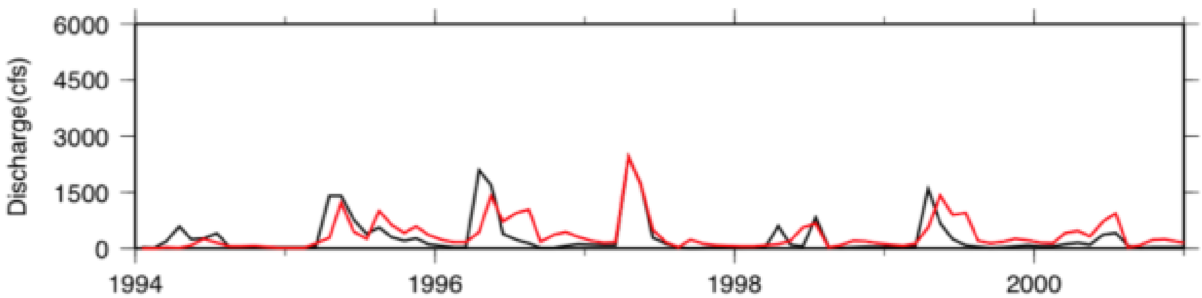


This work has resulted in a recent paper published in the Journal of Hydrology and has been lead by a PhD student from the University of Manitoba, Sitotaw Yirdaw.

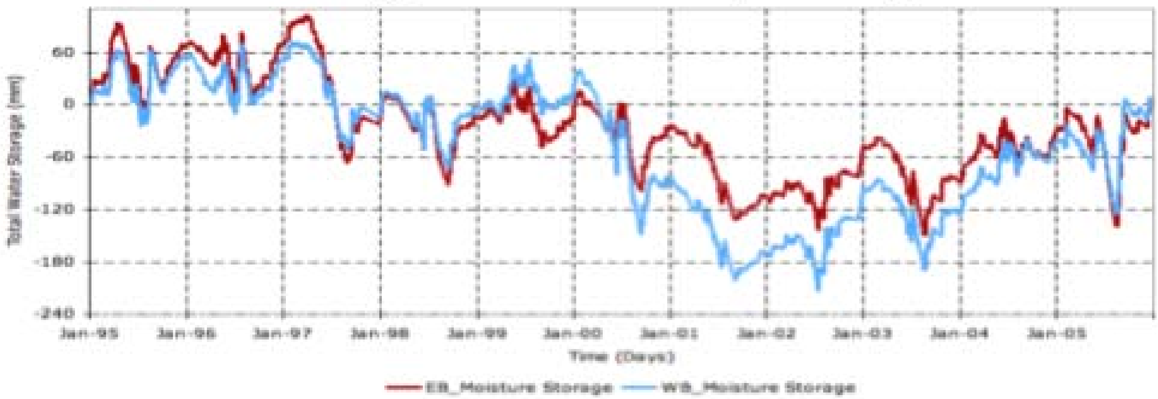
Theme 2: Improve the understanding of the processes and feedbacks governing the formation, evolution, cessation and structure of the drought.

Assiniboine River Basin Hydrologic Modelling: The larger area to the north and west of the ADA is known as the Upper Assiniboine River basin. The DRI science committee has selected two Prairie study areas for more detailed study; i) the South Saskatchewan River Basin and ii) the Assiniboine River basin.

Ascertaining the role of the regional soil moisture as one of the slow drivers of the Canadian Prairie drought was one of the main focus of our research in the course of the year 2007-2008. Availability of measured or simulated soil moisture dataset or total water storage estimation over the Prairie in general has gone unmeasured and these kinds of data are of great importance if we must arrive at a better understanding of the exchanges in the water and energy cycles, and how these tie into the idea of drought evolution, continuation and cessation over this region. Using the land surface hydrologic model, VIC and other time series analysis approach such as the wavelet power spectrum, we attempted an estimation of the inherent memory in the pores of the soil up to a depth of about 1.5 metres. This was subsequently related to the integral timescale of the atmospheric process such as the precipitation field obtained from Environment Canada station over the 13000 km^2 Upper Assiniboine River Basin at the Kamsack outlet. The plot below shows the results of streamflow modelling using VIC for the gauged outlet at Kamsack.



Soil moisture from the calibrated VIC model is used to understand the memory structure of drought. An understanding of the long-term memory in the subsurface soil moisture is desirable because this helps to sustain such climate anomalies as drought over the Prairie. The intent here is to explore and incorporate this knowledge of the long-term memory into our model and to use this for short-term soil moisture forecasting over the domain. Again, since persistence in the soil moisture is translated into persistence in the near-surface atmospheric fields such as precipitation, temperature and humidity, this approach was taken with the hope that it could help us address the question of why the recent drought continued for the period it did. The plot below shows the decline of soil moisture through the drought period from the calibrated VIC model when forced with observations from an energy balance and a water balance approach.



Additional research task will involved the use of the total water storage estimation from the GRACE satellite in validating the computed total water storage from the macroscale hydrologic model, VIC, the outcome from this process is inconclusive as at yet. Similarly, assessing and validating other storage measurements such as snow water equivalent (SWE) and groundwater well lysimeter from Garth van der Kamp will be assessed over the Upper Assiniboine River Basin. By way of summarizing, our research effort for the year 2008 was essentially focused on the simulation of the different moisture stores over the Prairie and the validation of these results using available meterological dataset.

This work has generated a number of conference publications including the upcoming Canadian Society of Civil Engineering (CSCE) conference in St. John's, NL. This work has been lead by a PhD student from Memorial University, Clement Agboma.

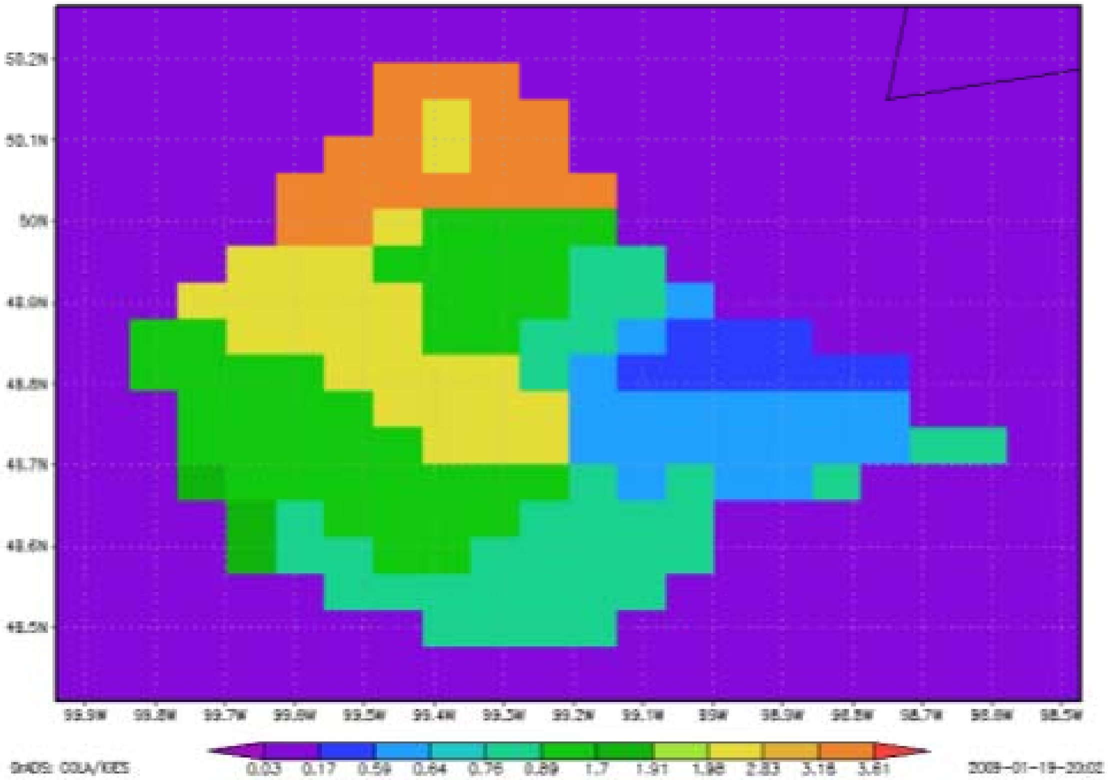
Theme 3: Assess and reduce uncertainties in the prediction of drought and its structure.

Groundwater Model Development: An aspect of prediction that holds great importance during drought is the quantification of the groundwater resources. The role of groundwater in starting, ending and continuing drought is presently unknown. However, we hypothesize that those groundwater boundaries that support the supply of soil moisture to the surface and to plants provide additional memory to the climate system that may influence the development of multi-year drought. Certainly the supply of groundwater resources take on great value as other surface water sources become scarce during drought periods. However, there may well be feedbacks to the climate system as drought conditions evolve. Understanding how groundwater resources response during drought is the subject of this sub-project.

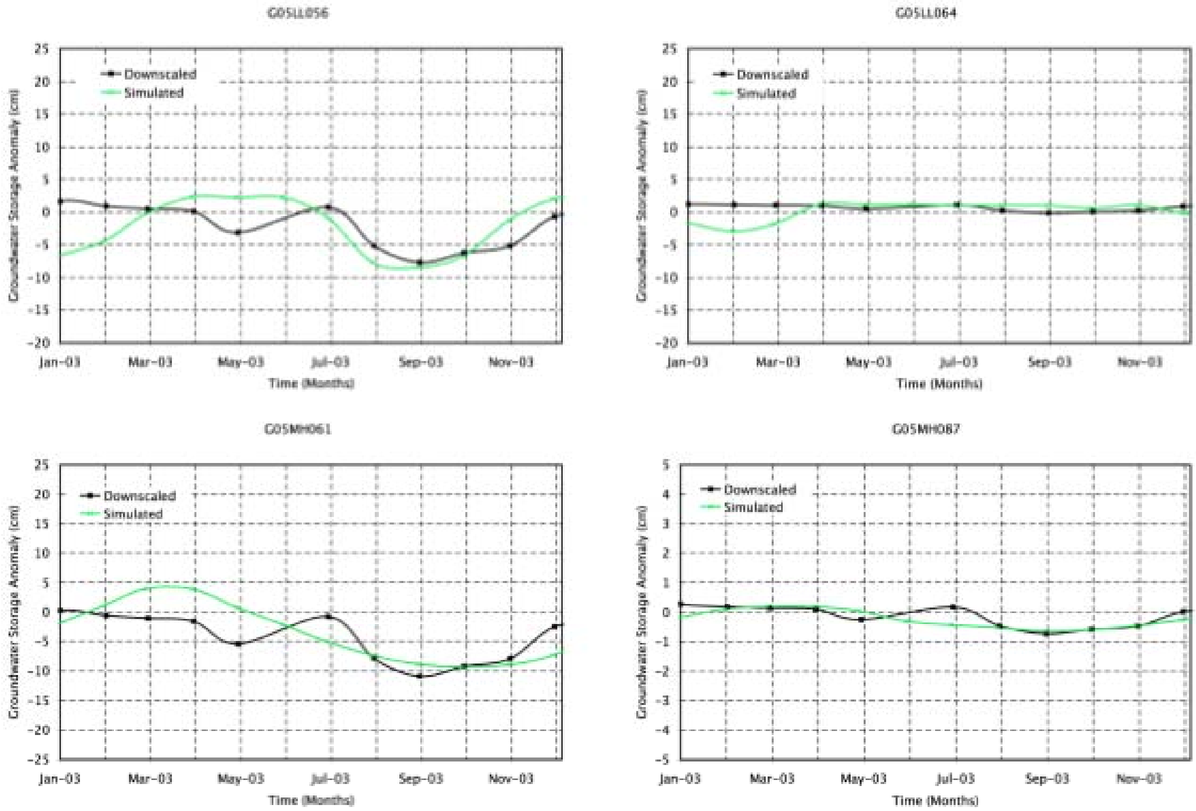
To date, we have focused our attention on the Assiniboine Delta Aquifer (ADA) area of southwestern Manitoba to develop modelling tools that will allow the description of groundwater resources within the framework of current land surface schemes. This work is being lead by Dr. Allan Woodbury's group at the University of Manitoba, with a post-doctorial fellow, Dr. Youssef Loukili, are developing a 2-D groundwater modelling scheme, known as SABAE, that can be incorporated within the CLASS and eventually to the MESH modelling framework. Dr. Loukili has moved on to other employment but has published a portion of the work in the Vadose Zone Journal. The model development work of SABAE has been transferred to Dr. Lei Wen at McGill University.

It support of this modelling effort, our group has been collaborating with Dr. Reed Maxwell at the at Lawrence Livermore National Laboratory and have adapted the ParFlow-CLM model to the Assiniboine Delta Aquifer (ADA) in Manitoba. This model couples the Common Land Model (CLM) scheme and a 3-D groundwater model developed to track solute movement in the subsurface. Because of its complexity, the ParFlow model is computationally expensive and requires large computational resources to complete simulations. ParFlow-CLM model has taken advantage of the computational resources associated within the Atlantic Computational Excellence Network (ACEnet) undertake integrations.

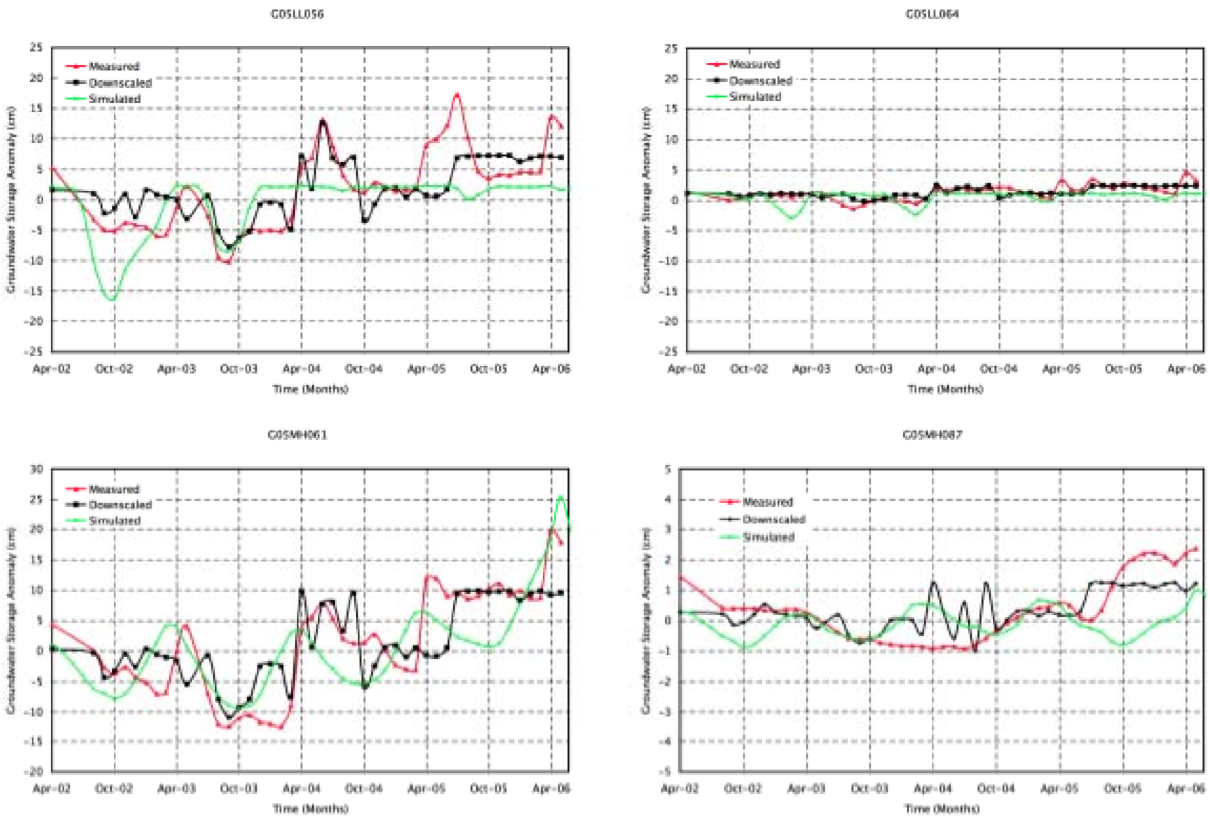
This work is now wrapping up after a successful year. Groundwater observations have been gathered from Manitoba Conversation and used to downscale GRACE satellite observations. From these results effective parameters of hydraulic conductivity where determined for the various sub-basins of the aquifer via a calibration process. These physical parameters will be quite useful once model testing with SABAE is underway. The map below plots the spatial distribution of hydraulic conductivity over the ADA



One measure of success in groundwater modelling is the reproduction of measured well water level verses simulated. 4 wells have been randomly selected from over 100 available observations for the calibration period and presented in the figure below.



From these calibrations, long term runs thought the drought period were performed. The results are presented below.



These modelling efforts have great application for Manitoba Conversation who manage the groundwater resources of the ADA. While the impacts of the 1999-2004 drought were not servere in southwestern Manitoba there is evidence of some impact on recovery of groundwater levels after 2004 in these plots. This work has been lead by a PhD student from the University of Manitoba, Sitotaw Yirdaw.

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

Over the next 18 months I intend to wind down may involvement in DRI. One PhD student, Sitotaw Yirdaw will graduate in May 2009 and Clement Aboma will continue to model the surface hydrology of the Assiniboine River basin using the VIC model. Our efforts along the three DRI themes are as follows:

Theme 1: Quantify the physical features of this recent drought

We will continue to explore the prairie water balance using the GRACE gravity satellite system and inter-compare these with independent observations of land surface moisture. This new remote sensing technique has great potential in providing a means to initialize moisture in atmospheric forecast schemes. In addition to GRACE observations we intend to utilize remotely sensed snow water equivalent (SWE) data and observations from groundwater well lysimeters.

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

The feedback of drought to the atmosphere takes place through the interaction with the land surface. Current hydrologic models generate streamflow contributions based, to a large extent, on the slope of the land surface as the driving force. However, prairie hydrologic models must permit runoff generation with little to no land surface gradient and the allowance of large, near surface moisture storage capacity. These complexities point away from slope based approaches such as WATCLASS toward those in which to catchment area increases and decreases depending on the amount of moisture stored in the land surface. Models such as VIC and TOPMODEL operate with a variable saturated area and their runoff generation formulations lend themselves more readily to the prairie environment. Here we will continue to explore the Upper Assiniboine Basin in Saskatchewan to test these model formulations in this larger 13,000 km^2 area.

We will focus on modelling with VIC to incorporate ineffective flow areas into the model structure. We also intend to continue to explore the influence of the land surface in the evolution of drought by analysis of the patterns of soil moisture deficits in the Assiniboine River basin.

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

We feel that the inclusion of saturated groundwater simulations will have an impact on the response of the land surface to moisture inputs that may well feedback to the evolution of multi-year drought through the long memory presistence of groundwater storage. Use of the ParFlow coupled land surface and groundwater models has shown that there are significant changes to the atmospheric feedback when long memory processes such as groundwater have been included in coupled atmospheric - land surface – groundwater simulations. We have used this modelling tool to explore the Assiniboine Delta Aquifer (ADA). While promising results have been achieved, the extension of these modelling results to other basin in region will remain undone. With only 1.5 years remaining in the project, there is little time to recruit a new student to continue the work of Sitotaw Yirdaw. It s hoped that the continued development of the SABAE model will continue and that the ParFlow model may be transferred to another student at the University of Manitoba. It is intended that the SABAE model will be less costly simulation tool that may eventually find application in limited area atmospheric – land surface – groundwater simulations that can be applied over large geographic areas.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

1. GRACE satellite data has been downscaled to provide a data-driven approach to determine month-to-month changes in individual water well observation for the Assiniboine Delta Aquifer. Based these simple models, it would be possible to assess climatic impacts of groundwater resources in this area.
2. Modelling with the VIC land surface scheme is underway in the Upper Assiniboine River basin with parameter sensitivity studies underway to allow model calibration over a 16-year period.
3. Development of the SABAE groundwater model, being developed as part of DRI, will be supported by the concurrent evaluation of the Assiniboine Delta Aquifer area using the ParFlow simulation tool.

2.2 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);**

Models of land surface and groundwater are of specific interest to provincial agencies. Development of these tools has been received positively from the Saskatchewan Watershed Authority and Manitoba Water Stewardship

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**

  Collaboration with Kit Szato and Daniel Caya have reinforced the important linkage in between the land surface and atmosphere in closing the water balance.

  Collaboration with Allan Woodbury has started the development of groundwater simulation within atmospheric models. These tools will have greater importance in validating the results of atmospheric simulations during the drought due to low streamflow response "signal" as surface moisture signals decline during the drought.

- **Whether and how it has improved the reliability of predictive methods;**

  The prediction of mass changes in the land surface due to moisture as measured by the GRACE satellite system has shown a surprisingly good agreement with the GEM analysis data and groundwater wells that have been analysed. Providing these integrated assessments of GEM provide greater confidence in these forecast tools.

  Use of models such as ParFlow and VIC in the prairie environment also lend themselves to improved prediction.

- **The impact of the project on your own institution;**

  Memorial University has benefited by funding two Ph.D. students who are studying in Atlantic Canada.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**

  DRI activities have lead to increased exposure to partner organizations such as provincial government agencies, Manitoba Hydro and Ouranus. No new funding has emerged from these agencies as yet, however.

- **Any current (or potential) commercial or social applications, which the results may have;**

Manitoba hydro has a vested interest in understanding drought processes and the probability of drought reoccurrence. Outcomes from DRI, while not directed toward assessing the drought from a reoccurrance likelihood could be important for short term planning associated with their reservoir operations.

The potato growing industry associated with the Assiniboine Delta Aquifer are very interested in knowing the quantity of groundwater that is available on a sustainable basis. This water has considerable value and the research to understand this resource's drought impact is important to them.

- **Links with international initiatives and the potential impact of these;**
  The importance of the increased memory associated with the incorporation of groundwater resources within atmospheric simulations is beginning to emerge. We have initiated a collaboration with Dr. Reed Maxwell at the Lawrence Livermore National Laboratory to foster the continuation of these activities.

- **Anticipated benefits of the work for Canadians.**
  Understanding drought processes and improving prediction and monitoring of drought can directly benefit Canadians if drought science is incorporated in government policy. Models being developed and information sources being assessed have the potential to providing increased predictive power for groundwater and surface water resources.

3.0 <u>Dissemination</u>

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Youssef Loukili, Allan D. Woodbury, and Kenneth R. Snelgrove (2008) SABAE-HW: An Enhanced Water Balance Prediction in the Canadian Land Surface Scheme Compared with Existing Models, Vadose Zone J. 7: 865-877.

Yirdaw, S.Z., Snelgrove, K.R., Agboma, C.O. (2008) GRACE satellite observations of terrestrial moisture changes for drought characterization in the Canadian Prairie

, Journal of Hydrology, 356 (1), p.84-92, Jul 2008

Conference presentations:

Agboma, C.O. and K.R Snelgrove (2008), Patterns Of Moisture Storage During Canadian Prairie Drought, Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract H11E-0817

Others:

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Data used in the project is produced from other sources. Web sites from which source has been extracted have been posted on the DRI web site.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

Various articles in Memorial publications. See for example:

Luminus Magazine v32, no.2 p.12-13. [Memorial University Alumini Magazine]

Benchmarks Magazine, Winter 2007, p.12 [Faculty of Engineering Alumini Magazine]

Ronald Stewart

2008 DRI Progress Report

Drought, Clouds and Precipitation

Principal Investigator: Ronald Stewart, McGill University

This study will focus on the flow of water through clouds and precipitating systems to the surface within and adjacent to drought regions. In particular, it will focus episodic events that produced heavy, widespread precipitation and on thresholds that must be exceeded before precipitation can reach the surface. Key issues include the relative contributions of water vapour from external and local moisture sources, the efficiency through which cloud systems convert this water vapour to precipitation, the possible role of the drought environment in enhancing the strength and/or efficiency of some precipitating systems, and the production of scattered, partially drought-alleviating precipitation. The ensuing insight will be related to surface and sub-surface moisture conditions in collaboration with other DRI scientists. Throughout the effort, the degree to which current models are able to capture the flow of water through the system will be assessed.

In particular, the objectives are:

6. To better understand the flow of water vapour into and through clouds and precipitating systems to the surface within and adjacent to drought regions

7. To apply these advances to water issues and to prediction capabilities

This research will contribute to each of the funded themes of DRI through:

- Quantitative assessment of several branches of the water cycle in relation to drought
- Assessment of simulation and predictive models and recommendations for improvement

1.0 Progress in 2008

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2007-08. How are the original milestones being met? List the key objectives and results achieved to date as well as any relevant application(s) of the results.

Theme 1:

Characterization of drought within this theme in 2008 was associated with cloud fields as well as virga, major precipitation and cold season features.

Little is known about cloud climatology during drought. But, information on clouds has been analyzer is now readily available from satellite data as far back as the early 1980’s. Surface Radiation Budget (SRB) satellite data has been applied to the Prairies. This analysis indicated that, in general terms, clouds were still quite frequent during the recent drought. Even when applied to the regions experiencing the greatest impacts, there were still many clouds present. This currently covers the period 1984-2004. There are several parameters associated with this dataset.

In addition, operational radar data from several sites over the Prairies have been acquired for major events occurring at different times during the drought. This radar information is being analyzed and will contribute to the drought's characterization.

Some aspects of the cold season were also characterized. It was shown, for example, that several locations across the Prairies were warmer than normal; there was also a corresponding increase in the instances in which surface temperatures passed through 0°C; and there was a decrease in instances of blowing snow.

Theme 2:

Over the past year, the main Theme 2 issues include cloud, precipitation anomalies, and individual storms. A brief summary of progress on these issues is listed below.

Satellite-based analyses analyses of cloud cover throughout the Canadian Prairies have been carried out. Despite the huge differences in monthly scale precipitation, cloud fields over similar temporal ranges are much less dramatic. This is perhaps not surprising since precipitation can often be generated by individual, short-lived convective clouds.

A detailed analysis was also conducted of the possible occurrence of virga. This was carried out for the soundings near Edmonton over the summer months of the 1999-2005 time period. An algorithm used elsewhere was applied to the soundings to infer the instances of virga. Results imply that of order 10-25% of the soundings were conducive to virga. Precipitation may be forming aloft but it wouldn't reach the surface. It is not yet known how such values compare with those of non-drought periods.

The CanGrid precipitation was used to characterize aspects of the drought. One of the ways through which this was done was simply to count the number of months when each grid over the Prairies was in drought. For the period 1999-2004, the peak number of months was 35. This was located along the northern Alberta-Saskatchewan border near Ft. McMurray. This particular grid was surrounded by other grids with very high values and this pattern of high number of grid boxes carried on towards the north-east. In contrast, some grids in south-east Manitoba experienced less than 15 months within drought conditions.

On the opposite extreme, the June 2002 major rainstorm is still being examined. This mammoth storm changed extremely dry conditions over the southern Prairies to above average conditions. Research on this storm had started more than a year ago and it is coming to an end. A key suggestion is that the storm was actually made more intense because of the dry sub-cloud region present in drought that facilitated rapid evaporation of falling precipitation and this in turn altered storm dynamics.

Other instances of heavy precipitation are also being studied. By some measures, such extremes were more common during the drought than expected on the basis of background climatology. It is not clear how all these major precipitating events were produced. Some are believed to have been associated with deep convection and short duration. Others are believed to be more stratiform precipitation and long duration. Assessing such basic factors is critical to understanding the means through which major precipitation events occur in association with dryness. That is, it is addressing the issue of strong variability of wet-dry conditions.

Theme 3:

Theme 3 issues mainly focused on an examination of predictions during the drought as well as inferences of marginal precipitation and virga.

On a large scale perspective, operational seasonal predictions have been examined in order to assess in general terms their ability to predict precipitation anomalies during the recent drought. These predictions generally were poor with regard to predictions of summer precipitation in particular. At least some of this is linked with such models missing individual, major precipitation events. However, available data is not readily available for the whole drought period.

1.2 Next Year:

Over the next year, research focal points will be:

June 2002 storm: The study of this event will be wrapped up in terms of the meteorology. It is expected that a follow-on activity will focus on the impacts of this event on other features such as vegetation, river flows and perhaps drought migration.

Major precipitating storms: The occurrence of all major precipitation events during the drought will be carefully documented. Once established, the study will focus on the factors that led to such events and their impacts on the nature of the drought. Inferences will also be made of the extent to which such events have been captured within appropriate models.

Models and cloud fields: A systematic study will be undertaken of the ability of the regional climate model to simulate the satellite-derived cloud fields for the drought period. The satellite side of this has largely been done but now this will be compared against the model data.

From a Network perspective, the critical overall synthesis activity is underway. This process will take another 1-2 years to complete so that the end of DRI will coincide with the completion of this multi-authored article.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

The short term objectives of this project in 2008 were to characterize and to interpret some of the key internal features of drought. This includes the importance of marginal precipitation, the occurrence of major storm systems, and cold season features. All these have now been demonstrated and the next steps are to more fully understand the role of these factors on drought structure and evolution.

2.2 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.

This project so far has been addressing fundamental issues in association with drought. Issues such as marginal precipitation occurrence and individual storm events don't seem to have been examined in detail before yet they can be very important. As the research proceeds, its impacts will increase. This research is of considerable interest to students because it is addressing key aspects of a type of hazardous weather that has not been addressed before. There is tremendous opportunity for discovery.

2.3 The impact of the project on government policy development (federal, provincial or municipal);

At this point, my personal work probably does not have an impact on government policy.

2.4 How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation

It will in the future, particularly through the DRI synthesis article and through the legacy items of DRI.

2.5 Whether and how it has improved the reliability of predictive methods

This work has not yet led to improvements in predictive methods. Some model deficiencies are beginning to be identified though.

2.6 The impact of the project on your own institution;

It may lead to such increases but not yet. There may be in particular a small add-on through Manitoba Hydro but this is far from sure.

2**.7 Any current (or potential) commercial or social applications, which the results may have;**

2.8 Links with international initiatives and the potential impact of these;

The whole DRI effort is linked closely with international GEWEX and WCRP activities on extremes.

2.9 Anticipated benefits of the work for Canadians.

Anomalies related to the hydrological cycle are an enormous problem. DRI itself and its individual researchers addressing such issues will eventually contribute to being better able to cope with such features.

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.

Publications:

Stewart, R.E., J. Pomeroy and R. Lawford, 2008: A Drought Research Initiative for the Canadian Prairies. CMOS Bulletin, 36, 87-102.

Presentations (besides the DRI January 2008 workshop):

Stewart, R.E., 2008: Extremes around the world and their impacts. AGU, San Francisco.

Greene, H., R.E. Stewart and H. Leighton, 2008: Clouds during the recent drought over the Canadian Prairies. CMOS Congress, Kelowna, B.C.

Stewart, 2008: Extremes and GEWEX. CMOS Congress, Kelowna, B.C.

Conference Organization:

2008 Convenor of GEWEX Extremes workshop Vancouver

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

The radar data used in this study has been archived and will be made available to other researchers.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

(Insert text)

Geoff Strong

2008 DRI Progress Report

Project Title: Atmospheric Moisture and Thunderstorm Drought

Investigator: G.S. Strong

1.0 Progress (beginning January 2008 to end December 2008)

1.3 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:

Theme 1: Quantify the physical features of this recent drought:

c) 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.

(S1) Boundary Layer Moisture Cycling: Last year I reported two main results on moisture cycling using fixed station data. To recap those two results:

a. During excessively dry soil moisture periods when the *wilting point* has been exceeded, moisture cycling stops, interrupting the daily evapotranspiration cycle. This impacts not only plant growth, but also the daytime growth of cumulus clouds, which on the prairies, depend to a large extent on daily evapotranspiration, especially from grain crops.

b. An older (1992 St. Denis) dataset was resurrected to show that a very clear gradient of mixing ratio exceeding 1 g kg^{-1} between a wheat field and adjacent prairie grass was observed over a fixed micro-transect footprint of only 180 m, using standard mesonet stations over grass, a lush wheat crop, and a third station at the transition point.

The 2008 UNSTABLE field project presented opportunities to test these results a little further. A planned fixed micro-transect similar to (ii), but including three sets of instrumentation over the grain crop site to measure vertical moisture gradients, was not realized due to limited resources (manpower and time, even though instrumentation was available), and this has now been postponed to 2009 and a more impressive array of instrumentation including an eddy correlation tower and soil moisture transects at an existing site near Kenaston, SK, starting in June, 2009. However, during the course of investigating UNSTABLE-2008 *drylines* (reported below), continuous mobile measurements of pressure, temperature, and humidity at 15-second intervals provided an additional unique set of data that demonstrates the moisture gradients discussed in (ii) for a much larger footprint, while also demonstrating differences in moisture cycling over high soil moisture grain crops while driving through rural farming areas, from visibly lower moisture cycling while driving through small urbanized towns. An example is provided in ***Figure 1***, showing two transects (#2 and #3 of 6 that day) of temperature and mixing ratio (the absolute humidity) between the Millet overpass (about 25 km south of Edmonton International Airport on Highway 2) and the town of Blackfalds, a driving distance of 85 km along Highway 2 (the next town north of Red Deer).

Transect #2 (***Fig. 1a***) was conducted during late-morning (1545-1645 UTC) of 12 July 2008, and followed Highway 2 that is straddled by mostly grain crops on either side, and did not pass through any urbanized areas. Mixing ratios varied between 6 and 8 g kg^{-1}, with continuous fluctuations of about 0.5 g kg^{-1} about the average (although there is also a curious 10-minute cycle in the data). Plant available water (PAW) in the area varied from 50% (Olds) to as low as 23% (close to wilting point) at Lacombe (Brimelow, pers. comm.), which partially explains the relatively low values of mixing ratio (6-8 g kg^{-1}), although the amplitude of fluctuations suggest that there was still significant local evapotranspiration on 12 July.

This contrasts starkly with Transect #3 (***Fig. 1b***) near noon-hour (16:45-19:00 UTC), and which took a less-direct alternate route, mostly along Highway 2A that diverges eastward from Highway 2 at distances of up to 18 km. More importantly, this route takes in several urban centres, including the towns of Blackfalds, Lacombe, Ponoka, Hobemma Reserve, Wetaskiwin, and Millet. Time traversing or even stopping in each urban centre varied from 2 minutes (Millet) to 20 minutes (Lacombe and Wetaskiwin), but each urban sector is evident in ***Figure 1b***, and is summarized in ***Table 1***, which shows average and standard deviations of temperature and mixing ratio values for each sector.

The main interest in these data at present is in the mixing ratio, showing an average of 0.6 g kg^{-1} *higher through rural as opposed to urban areas, while the standard deviation of fluctuations for rural is double that of the urban areas, demonstrating the larger degree of moisture cycling. Similar results were obtained for transects through various towns in central Alberta on different days. These differences have implications for drought characterization that depends on underlying surfaces (urban versus rural, cropped versus grass or forest, etc.), and on the cycling of moisture, which bears direct relation to the occurrence of thunderstorms and thunderstorm/shower outbreak periods.* It is no secret that the Palliser Triangle, which experiences the most frequent and most severe droughts on the prairies, also has the highest frequency of severe storms, including lightning, large hail, and tornadoes.

More intensive analysis of these data is underway.

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

(S2) Convective Processes across Strong Moisture Gradients:

My 2007 report postulated similar processes at work between *dryline*-initiated thunderstorms over Alberta foothills, and thunderstorms that sometimes form at, and move along, the periphery of a persistent drought area. Such storms sometimes have the effect of helping to end a drought. Some data have now been collected to substantiate these possibilities.

The *dryline* is a *summer chinook* effect (Strong, 1982, 1986) over the Alberta foothills that often helps initiate severe thunderstorms in Alberta. *Chinooks* are essentially dry air subsiding off the front range of the Rockies that have been modified in its transit across the mountains, losing much of its Pacific moisture on the western upslope side. A key ingredient to this is the simple fact that *dry air is denser than moist air*, which is of course what allows a dry chinook (whether winter or summer case) to subside on the lee (Alberta) side, warming by compression at the dry adiabatic rate, then undercutting any low-level moisture, such as is often present beneath a summertime *capping lid* over the Alberta foothills. The dryline also transfers momentum from mountain-top level to the foothills, further contributing to convergence. These processes were significant factors in the Pine Lake tornadic storm of 14 July 2000. The storm was initiated on the east slopes of the foothills southwest of Red Deer where the dryline met the moist underrunning lid air, then moved almost due east, intensifying as it collected more boundary layer moisture (latent heat energy), and reaching its dramatic conclusion by spawning an F3 tornado over Pine Lake southeast of Red Deer. Moreover, the region south of Red Deer had been suffering under extreme drought conditions (mean available root zone soil moisture under 10%) all summer. Southerly winds persisted in the boundary layer (surface and 850 hPa levels) over southeastern Alberta all day on 14 July, so that the developing storm had dry air (the dryline) undercutting the moisture over central Alberta from the west and southwest, while the drought-stricken region provided undercutting dry air ahead of the storm on its southern flank.

During UNSTABLE-2008 (09-23 July), mobile transects were made across a number of drylines. One particular dryline on 13 July was instrumental in initiating two severe storm cells west of Rocky Mountain House, which moved southeast while dropping up to golfball-size hail in two rather long swaths from Rocky Mountain House through Innisfail and Three Hills. The dryline was traversed many times during mid-afternoon southwest of Sundre (see Figure 2), where it was stalled in a shallow valley (Deer Creek Flats) over the foothills. As Figure 2 indicates, this dryline was extremely sharp, with a mixing ratio gradient of 4 g kg^{-1} across less than 100 m. Even more surprising was the fact that while it was quasi-stationary for at least 3 hours (slopping back and forth across 5 km), no significant mixing took place between the dry and moist air.

It is believed that this analogy between meso-γ scale drylines and the larger scale moist/dry gradients associated with large regions of drought has significance for drought processes. Drought may be initiated as moisture cycling (and storms) are terminated over a region due to lowering soil moisture, while the cessation of drought may be signalled by an outbreak series of or even single thunderstorm events associated with the moisture cycling discussed under S1. Moreover, thunderstorms persistently occurring along the periphery of drought regions may actually help maintain the drought through dry downdrafts spreading out on either side along their tracks.

Analyses of S1/S2 are continuing using the mobile transects from both A-GAME (2003-05) and UNSTABLE (2008), along with fixed mesonets, special radiosonde soundings, GPS moisture, aircraft data, and radar/satellite imagery.

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

- **Diurnal Cycle of Moisture from Varying Land Cover:** The quantification of micro-scale drylines and of mesoscale moisture gradients across varying land cover such as between a wheat crop and prairie grass (as reported in notes for Theme 1 above) should be important input for the parameterization of numerical models.

1.2 **Describe your 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.**

a) **The moisture cycling research described in S1/S2 will be continued using more case studies from the current drought period.**
b) **Sounding data will be processed to analyze moisture cycling above surface during the 1998-2005 drought period.**
c) **Will carry out collection of micro-transect data from Kenaston during summer/2009, although analyses of these will extend beyond the DRI lifetime.**

2.0 **<u>Impact</u>**

2.1 **What short and medium term objectives have been achieved, or are anticipated;**

Short-term goals during this calendar year and progress achieved are as follows:

1) Complete moisture cycling analyses using surface and sounding climatological data.
2) Complete analysis of drylines from A-GAME (2003-05) and UNSTABLE (2008) field data, isolate cases with peripheral drought regions, and test hypotheses presented in S1/S2.
3) Analyze other cases involving severe convective storms on the periphery of drought regions, and determine related forcing factors.
4) Present results at CMOS Congress in Halifax.
5) Complete paper on A-GAME analyses and submit to A-O during winter/2009 (has implications for DRI).

2.2 **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); - N/A**
- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation; - increased collaborations with UofC, UofA, UofM, and federal government scientists through work on GPS moisture, drylines and UNSTABLE.**
- **Whether and how it has improved the reliability of predictive methods; - N/A**
- **The impact of the project on your own institution; - N/A**
- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships; -** not to date, mostly due my lack of formal attachment to any one institution (other than adjunct status at UofA where it has no impact at all).
- **Any current (or potential) commercial or social applications, which the results may have;** - nil
- **Links with international initiatives and the potential impact of these;** - nil
- **Anticipated benefits of the work for Canadians.** – too far in the distance to judge.

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.

- Paper presented at CMOS Congress, Kelowna, May 2008: *Thunderstorm-Drought Links*.
- I've also presented some of my DRI results to students in my physical geography course given each fall at The King's University College.

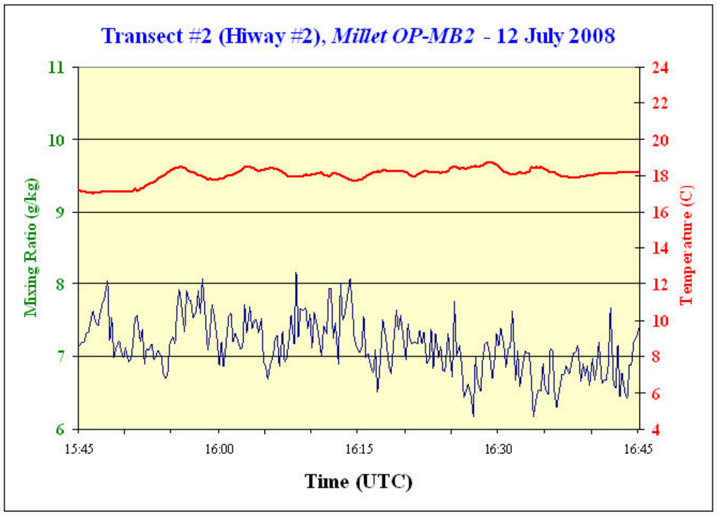
3.2 Describe data management sharing activities including organization of the metadata. Also, ~~is~~ are the data being archived, and how will these be made available to other researchers?

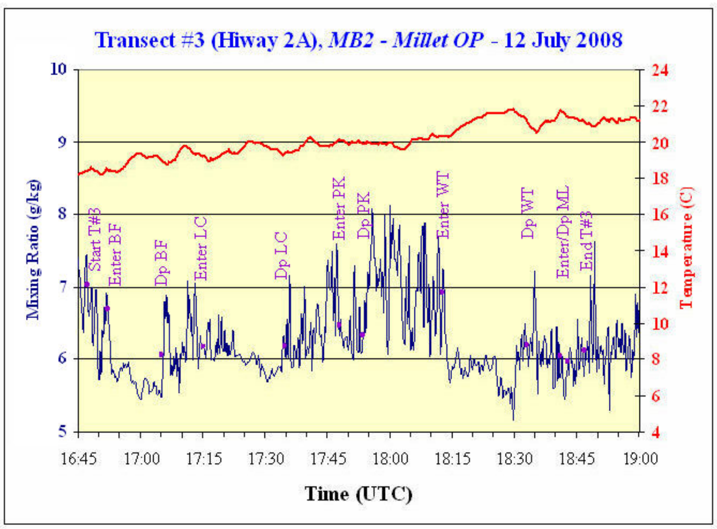
- All of my data are archived and can be made available to other DRI investigators.

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

- N/A

FIGURES


Transect #2 (Hiway #2), *Millet OP-MB2* - 12 July 2008
Mixing Ratio (g/kg)
Temperature (C)
Time (UTC)
15:45
16:00
16:15
16:30
16:45


Transect #3 (Hiway 2A), *MB2 - Millet OP* - 12 July 2008
Mixing Ratio (g/kg)
Temperature (C)
Time (UTC)
Start T#3
Enter BF
Dp BF
Enter LC
Dp LC
Enter PK
Dp PK
Enter WT
Dp WT
Enter/Dp ML
End T#3
16:45
17:00
17:15
17:30
17:45
18:00
18:15
18:30
18:45
19:00

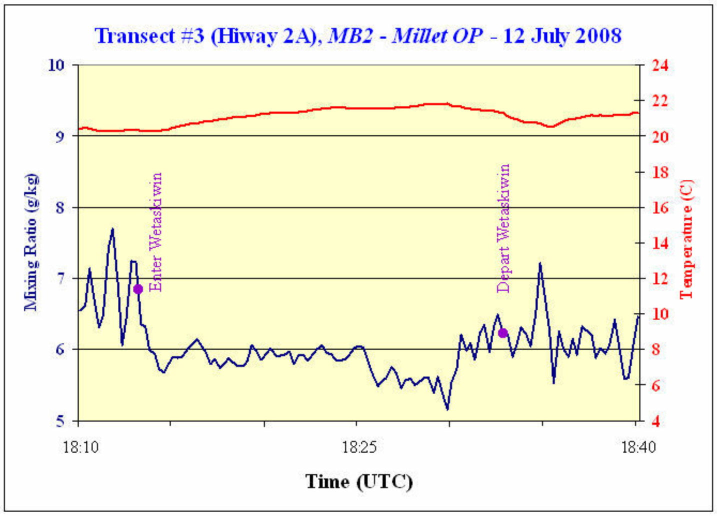


FIGURE 1: Transects of temperature (°C) and mixing ratio (g kg-1) Blackfalds to Millet, Alberta on 12 July 2008: (a) Transect #2 along Highway 2, all rural; (b) Transect #3 along Highway 2A, rural and urban; (c) exploded view of the Westaskiwin sector (1810-1840 UTC) of (b).

TABLE 1: Summary of mobile transects of temperature and mixing ratio for Blackfalds to Millet overpass via Highway 2A (Transect #3, Fig. 1b), 12 July 2008.

Transects of Temperature and Mixing Ratio, 12 July 2008

Transect	Sector	Start Time (UTC)	End Time (UTC)	Transit Time	Average T (C)	S.Dev. T (C)	Average MR (g/kg)	S.Dev. MR (g/kg)
3	MB2 to Millet Overpass (via Hiway 2A)	16:47	18:47	02:00	20.0	0.9	6.0	0.2
	- MB2 to Blackfalds	16:47	16:52	00:05	18.4	0.1	6.5	0.4
	- in Blackfalds	16:52	17:05	00:13	19.0	0.4	5.7	0.1
	- Blackfalds to Lacombe (via Hiway 2)	17:05	17:15	00:10	19.3	0.3	6.2	0.4
	- in Lacombe	17:15	17:35	00:20	19.5	0.3	6.0	0.5
	- Lacombe to Ponoka (via Hiway 2A)	17:35	17:48	00:13	19.8	0.2	6.5	0.5
	- in Ponoka	17:48	17:53	00:05	20.0	0.1	6.3	0.3
	- Ponoka to Hobemma	17:53	18:02	00:09	19.9	0.1	7.2	0.5
	- in Hobemma area	18:02	18:05	00:03	19.7	0.1	6.7	0.6
	- Hobemma to Wetaskiwin	18:05	18:13	00:08	20.2	0.1	6.9	0.5
	- in Wetaskiwin	18:13	18:33	00:20	21.2	0.4	5.9	0.3
	- Wetaskiwin to Millet	18:33	18:41	00:08	21.0	0.3	6.1	0.3
	- in Millet	18:41	18:43	00:02	21.5	0.1	5.8	0.2
	- Millet to Millet Overpass	18:43	18:47	00:04	21.2	0.1	6.0	0.2
	Total time & AVERAGE RURAL:			**01:00**	**19.9**	**0.90**	**6.5**	**0.41**
	Total time & AVERAGE URBAN:			**01:00**	**20.2**	**0.97**	**5.9**	**0.23**
		Difference (Rural - Urban):			-0.3	-0.07	0.6	0.18

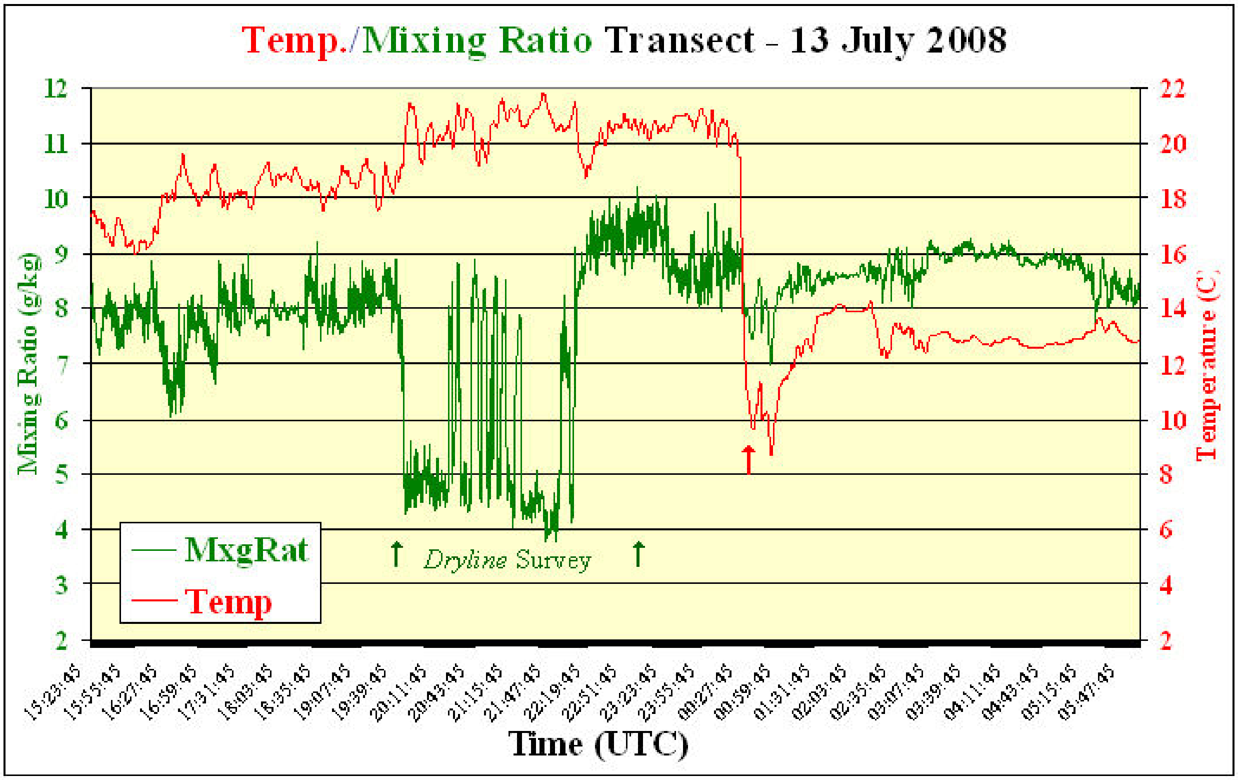


FIGURE 2: Multiple transects of temperature and mixing ratio across a sharp quasi-stationary *dryline* encountered at Deer Creek Flats (southwest of Sundre, AB) between 1945/2207 UTC on 13 July 2008. All transects occurred within a 5-km area. Sharp drop in temperature after 0025 UTC resulted from a downdraft beneath a resulting severe hailstorm some 120 km east-northeast of the dryline encounter.

Garth van der Kamp

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title:

Investigator: Garth van der Kamp

1.0 Progress (beginning January 2008 to end December 2008)

1.1. Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

Theme 1: Quantify the physical features of this recent drought:
d) 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.

Groundwater observation well data from across the prairies (MB, SK, AB) have been compiled in a consistent monthly format. The data for shallow water table wells show how groundwater storage was depleted during the drought and how it recovered afterwards. These data will be incorporated in a paper(s) to characterize the drought (Hanesiak et al., in prep). Some of the deep observation wells have been identified as acting like geological weighing lysimeters which provide information on changes of total moisture over large areas. Data from these wells are being compared with the moisture budgets derived from GRACE satellite data (with Ken Snelgrove).

A commercially available numerical model for flow and deformation in porous media has been adapted for the analysis of pore pressure data obtained from geological weighing lysimeters at the BERMS/Fluxnet Old Aspen site and at the Kernen Farm grassland site near Saskatoon (Anochikwa, MSC thesis in prep., U of Saskatchewan). This technique will allow improved hour-by-hour characterization of precipitation and evapotranspiration over an area of about 10 hectares for the period 1998-present which includes the drought.
Water level data for prairie wetlands, combined with the annual prairie-wide spring pond counts are being used to characterize how drought affects the water regime of the wetlands.

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

Data from the deep geological weighing lysimeter wells are being used to improve the way distributed hydrological models characterize moisture budgets (Marin et al., in prep.), particularly with regard to how well the models simulate evapotranspiration during the drought when soil moisture stress is extreme and deep-rooted vegetation tends to draw on deeper groundwater stores.

Water and energy flux data from the BERMS/Fluxnet forest sites in SK and from the grassland Fluxnet site in southern Alberta are being compared with particular emphasis on the water and energy fluxes during the drought years. The flux data indicate that grassland fluxes respond more strongly to drought conditions then the forest fluxes (Zhan et al., in prep.).

Flux data for a fen in the BERMS area (southern boreal forest, SK) have been compiled and analyzed with regard to variability of the fluxes during and after the drought (Sonnentag et al., in prep).

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

Observation well data and spring pond count data are being evaluated for their potential use in DEWS (drought early warning system). The long-term monthly data for observation wells are being used by DRI collaborator Sauchyn (U of Regina) in comparison with tree-ring data to characterize groundwater changes during pre-historic droughts in the prairie region (Perez Valdivia and Sauchyn, 2008).

1.2 **Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.**

Research will focus on completing work that is underway, as described above, and on preparation of papers.

2.0 <u>Impact</u>

2.1 What short and medium term objectives have been achieved, or are anticipated;

2.2 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.**

The geological weighing lysimeter method is showing increasing promise of wide application for testing hydrological models, for real-time assessments and forecasting of *droughts and floods, and for tracking of land-atmosphere moisture exchanges in relation to climate and weather prediction models.*

The compiled observation well records across the prairie region are being shared with the provincial groundwater agencies, and area being discussed in relation to how groundwater levels respond to drought and climate variability.

3.0 <u>Dissemination</u>

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Conference presentations:

*Hogan, J., **G. van der Kamp** and R. Schmidt, 2008. Groundwater-surface water interactions in a patterned fen in central Saskatchewan under a range of climate conditions. Presented at Healthy Peatlands session of the 2008 national conference of the Can Water Resources Assoc, Gimli, MB, June 16-19, 2008.*

***van der Kamp G**., D. Keir and M. Evans, 2008. Long-term water level changes in closed-basin lakes of the Canadian prairies. **Invited presentation**, 2008 Conference of the Alberta Lake Management Society, Sherwood Park AB, Sept. 18-20, 2008*

***van der Kamp, G**., 2008. Wetlands and climate in the Prairies. Invited presentation for the Saskatoon Environmental Society, March 12, 2008. Saskatoon SK.*

***van der Kamp, G**. 2008. Groundwater interactions with soil moisture and surface water. Prairie Drought Research Initiative (DRI) Workshop #3, January 17-19, 2008, Calgary, AB*

Others:

3,2, Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Observation well records have been submitted to the DRI data manager, including metadata.

3.3.. Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

Short article on groundwater springs for the Saskatoon Sun, July 20, 2008, emphasizing that springs provide water supplies and ecological refugia during droughts.

Elaine Wheaton

2008 DRI Progress Report

Project Title: Characterizing the 1999-2005 Canadian Prairie Drought: Drought Indices

Investigator: Barrie Bonsal and Elaine Wheaton

1.0 Progress (beginning January 2008 to end December 2008)

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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:

Theme 1: Quantify the physical features of this recent drought:
e) spatial and temporal features,

The main objective of this study is to quantify the extent and severity of the 1999 to 2005 Canadian Prairie drought at a variety of spatial and temporal scales using several standard meteorological drought indices, including the Palmer Drought Severity Index (PDSI), the Palmer Z Index and the Standard Precipitation Index (SPI).

Progress towards these objectives include:

- Three gridded temperature and precipitation datasets were evaluated to determine which was best suited to quantify drought characteristics over the Prairies
    - North American ANUSPLIN data (McKenney et al. 2006)
    - Canadian gridded climate data, CANGRID (as described in Zhang et al. 2000)
    - Climate Research Unit data (CRU TS 2.1, Mitchell and Jones, 2005).
- Calculation and comparison of monthly drought indices (PDSI and SPI) using the three gridded data sets over the Prairie Region from 1901 to 2005.
- Preliminary calculations of additional drought indices, including the Climate Moisture Index (CMI) developed by Ted Hogg (CFS).

Results showed significant differences among the gridded datasets, particularly in terms of precipitation. The assessment indicated that the ANUSPLIN dataset appeared to capture several intense precipitation events, as measured by the secondary climate stations, compared to the other datasets. SPI and PDSI values calculated using the ANUSPLIN data showed similar results. In both cases, drought conditions began to appear in southern Alberta in the summer of 2000 and had spread to cover most of southern and central Alberta and Saskatchewan by August 2001. Severe drought conditions persisted through to May 2002. In June 2002 in southern Alberta, and in August 2002 in central Saskatchewan, respectively, large precipitation events brought about major changes to the stable drought pattern that had persisted over the region. Drought conditions continued to be severe north of 52° latitude while to the south conditions became wet. These conditions continued through to June 2003 when once again it began to dry out across southern Alberta, Saskatchewan and Manitoba. The Prairie Provinces remained relatively dry up to April 2004. By May 2004 Manitoba was under normal to wet conditions, followed by Saskatchewan in August 2004, and Alberta in August 2005.

McKenney, D.W., J.H. Pedlar, P.Papadopol, and M.F. Hutchison. 2006. The development of 1901-2000 historical monthly climate models for Canada and the United States. Ag and Forest Met. 138:69-81.

Zhang, XB, L.A Vincent, W.D. Hogg, and A. Niitsoo. 2000. Temperature and precipitation trends in Canada during the 20th century. Atmosphere-Oceans. 38(3): 395-429.

Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high resolution grids. Int. J. Climatol.25: 693-712.

b) flows of atmospheric and terrestrial water and energy into and through the region, and their storage and redistribution within the region.

Not applicable

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

Not applicable

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

Not applicable

1.2 Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.

Future work will:

- Continue to use drought indices to examine the spatial, temporal patterns, and intensity of the 1999-2005 drought. In particular, our analysis of the Canadian prairie region will be expanded to include the northern United States.
- Develop methods to analyze the migration of the drought to assess how it evolved, where it persisted, and how it terminated.
- Relate drought patterns to agricultural and hydrological impacts

This research supports Theme 1 in that it aids in the description and quantification of the physical features of the drought across the Canadian Prairies between 1999 and 2005. In addition, this research will make a contribution to the understanding of the wide range of impacts associated with the drought and how these impacts relate to the intensity, timing, location, and duration of the drought.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

Continued research determined how well the three gridded datasets (ANUSPLIN, CANGRID, and CRU) represent observed station values. Each dataset was evaluated to determine which was best suited to quantify drought characteristics over the Prairies

The ANUSLPIN dataset was chosen for use in this study because it:

1. Appeared to capture several intense precipitation events, as measured by the smaller secondary climate stations, compared to the other datasets.
2. Covers the entire drought period of 1999 to 2005, and
3. provides data for all of North America allowing the examination of how conditions in the United States may have influenced the extent, severity and migration patterns of the drought on the Canadian prairies

Once the ANUSPLIN dataset was chosen the gridded data was used to calculate monthly drought indices (PDSI and SPI). Each month in the time series (1999-2005) was mapped using both GIS and Matlab. In addition, animations of the monthly drought indices over the Prairie Provinces have been created. These tools have provided some insight into some of the spatial and temporal changes in drought conditions across the prairies between 1999 and 2005.

Our next goal will be to relate these indices with observed drought impacts including but not limited to crop yields, pasture growth, water levels (dugouts) and aerosols (dust storms). These comparisons will provide an indication of the usefulness/applicability of drought indices.

2.2 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);** Our comparison of gridded climate data permits improved selection of such databases**.**

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;** Contacts for our work included many partners such as Ted Hogg (Canadian Forest Service), Dan McKenney (Canadian Forest Service), Paul Bullock (U of Manitoba), John Hanesiak (U of Manitoba)

- **Whether and how it has improved the reliability of predictive methods;** Not Applicable

- **The impact of the project on your own institution;** DRI work has several positive impacts on our institutions including the use of contacts, data and information to aid other research work. Research has contributed toward Environment Canada research mandates toward better understanding the extreme hydrologic events on the hydrology and ecology of Canada.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;** DRI has likely increased visibility of our institutions.

- **Any current (or potential) commercial or social applications, which the results may have;** The results have many socio-economic applications, some of which we are documenting in other project work as documented in section 1.6 with Theme 5 publications. These applications relate mostly to the vulnerability and adaptability of rural communities to water scarcity and climatic change.

- **Links with international initiatives and the potential impact of these;** DRI links well with our Institutional Adaptation to Climate Change project (funded by SSHRC) that compares the vulnerability and adaptability of rural communities regarding water scarcity and climate change.

- **Anticipated benefits of the work for Canadians.** We are just beginning to explore benefits and these include implications for water management, and community vulnerability.

3.0 Dissemination

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Conference presentations:

Meinert, A., B. Bonsal and E. Wheaton. 2008 January. *Characterizing the Climatological Nature of the 1999-2005 Drought in the Canadian Prairies: Data Sources and Issues.* Presentation to *the 2008 DRI Workshop*, Calgary, AB.

Meinert, A., B. Bonsal and E. Wheaton. 2008 September. *Characterizing the 1999-2005 Canadian Prairie Drought: Drought Indices and their Associated Input Variables.* Presentation to *the DRI Drought Characterization Workshop*, Winnipeg, MB.

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

Data are being managed by the DRI Data Managers

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

As a result of the presentations listed in section 1.6, the project helped increase public awareness of drought characteristics, impacts, vulnerability and of adaptations to drought.

Al Woodbury

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

2008 DRI Progress Report

Project Title: Drought Prediction and Vulnerability of Aquifers under Climate Change

Investigator: Dr. Allan Woodbury (woodbur@cc.umanitoba.ca)

Co-Investigators, Dr. Ken Snelgrove (Memorial), Dr. Lei Wen (McGill), Dr. Charles Lin (McGill), Dr. Youssef Loukili (Manitoba)

1.0 Progress (beginning January 2008 to end December 2008)

1.2 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. 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 Overall Objectives and Summary

Our long-term goal is to develop an efficient hydrological and numerical coupling of the Canadian land surface scheme with groundwater flow (rewrite of CLASS2.6/groundwater) , and also with the atmosphere through accurate lower boundary conditions. We succeeded in benchmarking of our improved version of the Canadian Land Surface Scheme CLASS, which we refer to as (SABAE-HW; Soil Atmosphere Boundary, Accurate Evaluations of Heat and Water). Inter-comparisons to SHAW, CLASS, HYDRUS-1D and HELP3 ensure the applicability and viability of our code. At this stage, we are continuing benchmarking and numerical tests of

SABAE-HW3D (gCLASS) which couples the flows in the unsaturated and saturated zones. The coupling strategy was chosen amongst others for efficiency and convergence reasons. We tested the code using synthetic data and comparing to Seep/W results. Our next effort will focus on running gCLASS over the study site, the Assiniboine Delta Aquifer (ADA), in stand-alone mode. Also, we plan to simulate a broad part of the Canadian prairie provinces with both CLASS and gCLASS as the underlying land surface schemes. As well, we plan to go ahead in numerical programming towards the ultimate coupling of gCLASS with the Canadian GCM, in order to allow more accurate exchanges of water and energy fluxes between the atmosphere and the earth surface. Thereby, we believe we are taking the right steps towards our main goal of developing and using the adequate “toolbox” of numerical simulators for drought studies over the Prairies. The overall objective remains to assist the DRI research efforts in trying to understand, assess and quantify the evolution of drought. Also, the inclusion of human practices in each of the model components (agriculture, pumping, wastes, and so on) will definitely allow us to study the influences on climate variability and change. Some specific efforts are described in the next two paragraphs:

1.1.2 Comparisons of SABAE (gCLASS-1D) to BOREAS Saskatchewan site (Collaborations with Dr. G. Van der Kamp)

The southern Old Jack Pine site (SSA-OJP) at the BOREAS Saskatchewan field station is a very rich area in terms of hydrology and meteorology data, was chosen to prove the accurate performance of SABAE. Soil type of the area is generally sand or sandy loam. Atmospheric data including long and short wave radiations, precipitation, air temperature, wind speed and specific humidity were available in 30 minute periods in 2005. Since SABAE has been developed for Δt=30 min, we had a great source of data to run this code. Vegetation type of this site is mostly very sparse green alder, thus they were classified as a need leaf in SABAE. Parameters related to this class (Maximum and minimum Leaf area Indices, maximum heights, visible albedos, canopy mass, near-infrared albedos and vegetation rooting depth) were collected. Based on the available data in Boreas website, 6 layers was applied for a soil column. The two first layers have a thickness of 15cm, with 30cm for the rest of layers. The total depth of soil column is 150 cm. We have two options for imposing the boundary condition at the bottom of the grid: water table and unit gradient. The UG boundary condition refers to free drainage from soil column into underneath layers and was considered as a lower boundary condition. Furthermore, we used the fixed point, based on the observed data (soil moisture and soil temperature), for upper boundary condition. In addition, the exact value of observed data at t=0 was applied for initial conditions. Since SABAE measures the value of soil moisture at the middle of each layer, we compared the results of SABAE with observed data at the depths of 7.5, 22.5, 45, 75 and 115cm. Unfortunately, the exact value of observed data at these points was not available. Thus we used the average of two layers for observed data and then compared them to the results of SABAE. We are trying to solve this problem by developing our simulations with refined mesh. The comparison between the results of SABAE with the observation field data shows that there is a good accuracy between the results of the code and the measured data with respect to the volume water content. But we have not obtained the reasonable results regarding soil temperature yet. After several simulations, we found the important effects of snow depth in soil temperature and even in soil moisture. Up to now, we have not been able to interpret the exact value of available snow depth in OJP site.

1.1.3 Experiments with SABAE-HW3D (gCLASS) package, Collaboration between Woodbury, Snelgrove and Lin's groups in DRI

The collaborative project has three objectives, which are:

1. Reproduce at McGill the results of the benchmark run from gCLASS (SABAE-HW3D) package;
2. Run gCLASS in stand-alone mode over the Prairies, or portions thereof, if parameters of the groundwater module are available, e.g., initial values of groundwater tables for each grid point;
3. Initiate efforts to couple gCLASS to the 1-D AGCM.

The project first objective has achieved. Lin's group has successful recompiled the main program of gCLASS (SABAEHW3D.F90) and its associated library (sabaelib.o) on the super-computer odin at McGill. They also reproduced the two results of benchmark runs provided by Woodbury's group at University of Manitoba.

1.2. **Describe your plans for research between January 2009 and June 2010 and outline how the expected results will support the deliverables and goals of DRI.**

1.7.1 BOREAS: Jack Pine Site

1. Interpreting the exact value of snow depth from the specific instrument (sensor SR50)
2. Extend soil column to at least 3 or 4 meters to reduce the seasonal heat transfer effects
3. Imposing water table boundary condition as a lower BC if the value of water table is available at the specific depth.
4. Applying the fined mesh (layers) to obtain value of soil moisture and soil temperature at depths similar to the observed depths.

5. Running the code for at least 3 years. This helps to reduce the effects of thawing and freezing over 3 years.

1.7.2 **Prairie Province Simulations (also Assiniboine Delta Aquifer)**

Lin's group (Wen) has prepared the necessary soil and vegetation parameter fields for the standard version of CLASS2.6 over a western Canada simulation domain (including the Prairies) with 100 x 90 grid points. The domain projection is polar stereographic, with a nominal horizontal resolution of 51 km at 60º north latitude. Applications of gCLASS over the Prairies could benefit greatly from those parameter fields.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

The idea of linking all the physics of water cycle processes relies basically on properly coupling the atmosphere, the land surface and groundwater components. The value of our efforts to achieve this goal by way of developed numerical methods was demonstrated in the course of our progress. As a matter of fact, our multilayer version of gCLASS with its user friendly input/output allowed us to persuade some other researchers to lead comparisons of their field measurements with the view of publishing joint papers. The time we devoted to understand and use other models (SHAW, HYDRUS-1D and HELP) gave us more confidence in coordination and work efforts. Then, so far as stated before, we did expand partners in a cross-disciplinary framework with Engineering and Applied Sciences (MUN), Geology (UofC) and Biosystems Engineering (UofM). Also, during the last international AGU 2007 fall meeting in San Francisco, we presented the first results of the coupled meteor-hydrological SABAE-HW3D model. Only a few researchers are on this critical path, and this proves again we are participating to the advance of this modern hydrological coupling trend with more powerful numerical and optimization tools. Moreover, it has to be noted that SABAE-HW keeps most of the improved CLASS surface physics, which gives it the potentiality of attracting more attention and partnership. We encourage the use of SABAE-HW by Canadian students, trainees and engineers inquiring the effect of climate on soil moisture, temperature, freezing and thawing. We also think about a special package for concerned public partners, which would enhance the outreach of the computational prediction concept (local and regional), and in return help fine tuning the weather conditions through communication of simple data collection.

2.2 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);**

  In addition to our work on drought (above) we have applied and received additional funding from the CWN. This work is complementary to our DRI initiative, with Woodbury and Professors Hendry, Parkin, and Thomson. As mentioned The Assiniboine Delta Aquifer (ADA) is a large unconfined, sand-and-gravel aquifer located in south central Manitoba. It is heavily relied upon as a source of drinking water and has been extensively developed for agriculture, which requires significant nutrient application. Results of recent research in the region have clearly indicated a high degree of risk to water quality from the nutrient management activities. In response to increasingly concerns with rising nutrient levels in surface and groundwater, new provincial moratoriums have been placed on the expansion of livestock enterprises and a regulatory framework is being developed for nutrient management. As mentioned, the new model, SABAE-HW (Soil-Atmosphere Boundary, Accurate Evaluations of Heat and Water), which is a soil-multilayer version of the Canadian Land Surface Scheme (CLASS) and a horizontal aquifer model, is undergoing prototype-testing. A major component of the proposed CWN research work will be to couple a physically-based, one-dimensional nitrogen transport module to the regional (SABAE-HW) model to quantify the nitrogen budgets of the ADA study site and others within our network of facilities.

- **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;**

We progressed in benchmarking SABAE-HW using actual atmospheric and soil data related to Pine Creek North, one of the thirteen sub-basins of the ADA. Up to five years stand-alone runs of SABAE-HW (gCLASS-1D), SHAW and CLASS gives an insight on the quality of results, and verifies the general applicability of our code in field situations. Indeed, contrasting solutions computed by the three codes (evaporation, water pond, snow depth, moisture, temperature, and so on) shows that SABAE-HW provides more accurate predictions than the original version of CLASS(2.6) that we reviewed.

- **The impact of the project on your own institution;**

The DRI workshops provided the framework for pan-university contacts and new partnerships. For example, Woodbury, Hanesiak, Akinremi and Buyian collaborated on an important issue in climate change research. Note there has been a great deal of interest in studying climate change through reconstructing ground surface temperatures (GST) from borehole measurements (BHT). Note that the magnitude of temperature increases reconstructed from BHT records seems to contrast however, with some proxy based reconstructions of surface air temperature (SAT) that indicate lower amounts of warming over the same period. We present data suggesting that ground and snow cover may bias climate reconstructions based on BHT in portions of the Canadian northwest. Eight sites west of the Canadian cordillera, were examined for long-term SAT and GST changes. At seven of these sites precise borehole temperature profiles are used for the first time since the 1960s, thereby exploring the linkage between GST and SAT. New readings were made at four of these locations. All sites showed significant increasing SAT trends, in terms of annual mean minimum and maximum temperatures. Over a 54 year period, the minimum temperatures increased between 1.1 ^{o}C and 1.5^{o}C while the maximum increased between 0.8 ^{o}C and 1.5 ^{o}C, among those eight stations. Observations of GST at those sites, however, showed no obvious climate induced perturbations. Therefore, we believe that a trend in our area towards an increase in SAT temperatures only over the winter and spring is being masked by freeze-thaw and latent energy effects. These results are important, particularly in northern locations where ground and snow cover may play an important role in creating a seasonal bias in GST reconstructions from borehole surveys.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**

Woodbury has, as of early February 2008 received additional partial support for one PhD student for a project titled " Water Sustainability under Climate Change and Increasing Demand: a One-Water Approach at the Watershed Scale" (Adam Wei, UBCO is the PI). Groundwater recharge data is critical for model calibration. Researchers have often used groundwater models, calibrated to current climate conditions, and altered their surface recharge function in a deliberate fashion in order to make statements about climate change impacts. Unfortunately, the methods chosen for altering recharge are based on evapotranspiration models that have been developed to work exclusively in current climates. These models are often based on temperature alone and do not reflect the changes in wind, cloud amounts or humidity that are also likely to be influenced by climate change. Jyrkama et al. found that use of a simple hydrologic model to produce spatially varied groundwater recharge patterns, significantly improved groundwater simulations. We intend to build on this approach by using a detailed Canadian Land Surface Scheme (gCLASS) in place of a simple estimation. This is justified since CLASS has been designed to integrate with components of GCMs and is better equipped to deal with increased the variability and shifts in mean conditions that are expected under climate change scenarios.

3.0 <u>Dissemination</u>

3.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Woodbury, A.D.., Snelgrove, K.R., Loukili, Y., and S. Yirdaw-Zeleke, Climate change assessment over the Assiniboine Delta Aquifer, Geological Society America, 2005 Salt Lake City Annual Meeting (October 16–19, 2005, Invited)

Loukili, Y., Woodbury, A.D., and K.R. Snelgrove, SABAE-HW – an enhancement of the water balance prediction in the Canadian Land Surface Scheme, 2006 San Francisco, AGU fall meeting (December 11-15, 2006)

Loukili, Y. and A.D. Woodbury, SABAE-HW3D: a Meteor-Hydrological Model Coupling the Land Surface to Groundwater Flow, *88*(52), Fall Meet. Suppl., Abstract H33C-1449. 2007.

Loukili, Y., Woodbury, A.D. and K. R. Snelgrove, SABAE-HW – An enhancement of the water balance prediction in the Canadian Land Surface Scheme, *Vadose Zone J.*, 7(3), 865-877.

Woodbury, A.D., H. Bhuyian, J. Hanisak, and O.O. Akinremi, Observations of northern latitude ground-surface and surface-air temperatures, Submitted to: *Geop. Res. Lett. (2008)*

3.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?

none

3.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

DRI workshops and AGU presentations