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

Final Progress Report

Project Title:
Diagnostic Analyses of the Prairies Drought

DRI Investigator: John R. Gyakum

1.0 Project Work

1.1 **Provide a summary description of a) the objectives of the study, b) the scientific findings and c) the project work undertaken.**

Much of the following text is taken from the January 11, 2010 progress report, with the primary updates occurring from the recently completed M. Sc. thesis of Lisa Hryciw.

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

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.
> 3) An analysis of the precipitation structures associated with various synoptic flow regimes during the drought.

Results achieved include:

1. We find that the recent Prairie drought, when analyzed on seasonal time scales, 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 associated refereed paper (Roberge et al. 2009) 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 now completing a comprehensive analysis of the initiation of the 1999-2004 drought, with a focus on the diabatic ridging associated with an extreme case of poleward water vapor transport discovered by Roberge at al. (2009). Our modeling studies have shown that the latent heating associated with explosive cyclogenesis in the northeast Pacific Basin is responsible for the the tropopause ridging in Alaska, and in the Northwest Territories. This ridge is shown to drive continental-scale descent that is in turn responsible for the deficit of precipitation throughout interior North America that persists for both September and October 1999.

2. 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. The details of these flow configurations were provided in the 2008 report.

A. 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.

B. 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.

C. 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.

D. Detailed analysis of mesoscale, synoptic-scale, and planetary-scale circulation anomalies associated with the initiation of the 1999-2004 Canadian Drought

We focus on the early autumn period of 1999, during which several, evidently disparate, meteorological events occurred. These events include an explosive cyclogenesis in the Gulf of Alaska, an historic storm surge event along the Beaufort coast, and the beginning of the 1999-2004 Canadian Prairie drought.

We examine the relevant dynamics associated with each of these extreme events, followed by a discussion of their linkages. The explosive cyclogenesis in the Gulf of Alaska was associated with anomalously strong tropospheric moisture transports into the Alaskan coastal range, and synoptic-scale diabatic ridging. This synoptic-scale ridging contributes northwesterly surface winds associated with the extreme Beaufort coastal storm surge event. The planetary ridging throughout western North America provided the large-scale forcing for subsidence throughout the North American interior, kicking off the longer-term drought.

1.3 **Describe the tangible results or the measurable outputs generated by the project and how these results have been taken up by user groups for policy development or operational improvements.**

Our results have demonstrated the multi-scale nature of droughts, and their intimate relationship to both synoptic-scale, mesoscale, and planetary-scale processes. The results may be used by both operational forecasters of both weather and climate, and also by researchers.

2.0 Impact

2.1 Describe in broad terms how your work has contributed to the overall objectives of DRI and to our scientific understanding of drought.

We have provided an enhanced understanding of synoptic-scale modulation of the drought process.

2.2 Describe the significance / impact of the results in terms of some or all of the following areas:

Our project has continuing relevance for Dr. Gyakum's collaboration with 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, and by an IPY grant, for Ph. D. student, Ms. Jessica Cox Turner. There will be three refereed papers coming from Dr. Turner's dissertation.

Lisa Hryciw's M. Sc. thesis will have an impact on both short-term and longer term forecasting, as she has identified a rich spectrum of synoptic processes modulating the drought in the Canadian Prairies.

4.0 Reverse Impact Statement

4.1 Provide a reverse impact statement, describing what would have happened in terms of the project, the resulting science and the impacts on users/stakeholders, if the work had not been funded by CFCAS.

Lisa Hryciw's M. Sc. thesis focusing on the Canadian Prairie drought would not have been produced.

5.0 Follow-on Science

5.1. Based on the findings of your research identify any outstanding scientific questions that need to be addressed in future drought studies.

We need to focus on the generation and decay phases of droughts, with a particular emphasis on the phenomenon of blocking.

6.0 Dissemination

6.1 Provide information on the 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 publications (students and postdoctoral fellows are in bold lettering:

1. **Knowland, K. E.,** J. R. Gyakum, and C. A. Lin, 2010: A study of the meteorological conditions associated with anomalously early and late openings of a Northwest Territories winter road. *Arctic,* **63**, 227-239.
2. **Turner, J.,** and J. R. Gyakum, 2010: Trends in Canadian surface temperature variability in the context of climate change. *Atmos.-Ocean*, 48, 147-162.
3. **Roberge, A.,** J. R. Gyakum, and **E. Atallah**, 2009: Analysis of intense poleward water vapor transports into high latitudes of western North America. *Wea. Forecasting*, 24, 1732-1747.
4. Kochtubajda, B., M. D. Flannigan, J. R. Gyakum, R. E. Stewart, K. A. Logan, and T.-V. Nguyen, 2006: Lightning and fires in the Northwest Territories and responses to future climate change. *Arctic*, **59**, 211-221.

Refereed publications submitted:

1. **Small, D., E. Atallah**, and J. R. Gyakum, 2010: Wind regimes at Tuktoyaktuk conducive for high wind events. *J. Climatology and Appl. Meteorology*, submitted.
2. **Turner, J. K.,** and J. R. Gyakum, 2010b: The development of Arctic air masses in Northwest Canada and their behavior in a warming climate. *J. Climate*, submitted.

Conference presentations (2010 only, as earlier presentations are located in previous yearly- reports:

Hryciw, Lisa: Meteorological Analysis of the 1999-2005 Canadian Prairie Drought; CMOS (2010)

Hryciw, Lisa: Meteorological Analysis of the 1999-2005 Canadian Prairie Drought; DRI Workshop; May 2010

Hryciw, Lisa: Meteorological Analysis of the 1999-2005 Canadian Prairie Drought; AGU, December 2010

Gyakum, John: Diagnosing meteorological drought mechanisms with global and regional reanalysis data; DRI Workshop; May 2010

6.2 Describe data management/sharing activities including organization of the metadata. Also, are the data being archived, and how will they 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.

6.3 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 continuing to collaborate with the community of Deline, NWT, on the issue of climate change.

7.0 <u>Training</u>

7.1 Quantify student and PDF involvement (indicate the level of each: undergraduate, masters, doctorate or PDF). If possible and within the Federal Privacy Act rules governing the collection of personal information, provide a general indication of their subsequent employment (i.e., university, industry, government, other, etc.), and indicate whether the employment was foreign or domestic.

Ph. D. Thesis:

1. Jessica Turner: Doctoral dissertation, entitled "The causes, variability and behavior in a warming world of the coldest winter-season Canadian temperatures and their associated Arctic air masses", 2010. 189 pp.

M. Sc. Theses:

2. Florian von Appen, Master's thesis entitled "The development of a warm-season blocking index for the Northern Hemisphere". 2007. 98 pp.
3. Alain Roberge. Master's thesis entitled "Analysis of intense sub-tropical moisture transports into high latitudes of western North America". 2008. 59 pp.
4. Katherine Emma Knowland (with Charles Lin). Master's thesis entitled "A study of the meteorological conditions associated with anomalously early and anomalously late openings of a Northwest Territories winter road". 2008. 71 pp.
5. David Small. Master's thesis entitled "Beaufort coast wind climatology and case study of a high wind event". 2010. 96 pp.
6. Lisa Hryciw. Master's thesis entitled "Meteorological analysis and historical perspective of the 1999–2005 Canadian Prairie drought". 2010. 86 pp.