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: Drought, Clouds and Precipitation
DRI Investigator: Ronald Stewart, University of Manitoba

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.

a. Objectives

This study focused on the flow of water through clouds and precipitating systems to the surface within and adjacent to drought regions. In particular, it focused on episodic events that produced heavy, widespread precipitation and on thresholds that must be exceeded before precipitation can reach the surface. Key issues included 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. 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:

- To better understand the flow of water vapour into and through clouds and precipitating systems to the surface within and adjacent to drought regions
- To apply these advances to overall drought problems, 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

b. scientific findings

There are numerous important findings. In no particular order, a few of these include:

- The 1999-2005 drought was a long way from being cloud-free; cloud fraction was just slightly below normal.
- Virga was common even when locations were experiencing the lowest precipitation on record.
- Record-breaking low precipitation can be linked with a normal number of days having precipitation

- Major storms can be made more intense due to storm-scale interactions with the dry drought environment.
- Cold conditions lead to drought just as effectively as hot conditions.
- Meteorological drought exhibits many types, not just hot, cloud-free and calm and long-lived drought can move between these different types.

c. project work undertaken

The research was broken down into the examination of six sub-issues. These are briefly summarized below:

cloud fields:

Little is known about cloud climatology during drought. Surface Radiation Budget (SRB) satellite data has 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.

virga:

A detailed analysis was also conducted of the occurrence of virga. This was carried out for the soundings near Edmonton over the summer months of the 1999-2005 time period and from radar data in the vicinity of Calgary, Edmonton and Saskatoon. The radar-based data illustrates, for example, that virga was sometimes more prevalent over these sites than precipitation at the surface. In addition, the average cloud base during virga events was <0C, implying that sublimation of particles initially occurred as opposed to evaporation. This generally means a more rapid mass loss, thereby promoting dry conditions at the surface.

mammoth storm:

A several-year long effort to study the June 2002 major rainstorm has largely been completed. 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.

severe storm occurrence:

Other instances of heavy precipitation during the drought have also being studied. By some measures, such extremes were more common during the drought than expected on the basis of background climatology. The factors leading to these major precipitating events were variable. Some were associated with deep convection and short duration. Others were 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.

cold drought:

One recent development was the concept of 'cold drought', a term I coined to explain the lack of precipitation under below-normal temperatures. A small team of researchers is now examining the past occurrence of such events.

meteorological drought 'types':

Cold drought is part of an overall idea I have to consider the various types of meteorological drought that actually occur. Hot and summary are but two elements. This issue is summarized later on in this report.

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.

Tangible results include dataset development (as described elsewhere) and scientific progress that is having impacts elsewhere.

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.

This project has mainly 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. Virga was very common during the drought; precipitation was produced aloft but did not quite reach the surface. As well, it was also shown that the dry drought conditions can, under the right conditions, actually enhance a storm and lead to more precipitation. The dry environment and the storm can interact. As time progresses, the impacts of all this insight will increase. It will, for example, impose more stringent requirements on models that purport to simulate and predict drought.

A conscious decision was made early on to focus on such research issues that has not been studied at all or has been studied in only a cursory manner. Others are working on more 'traditional' approaches to drought research and that area is therefore well covered within DRI.

One key insight is that meteorological drought has different 'types'. The traditional concept (which certainly occurs of course) is that drought is linked with clear skies and high temperatures. it can also occur under cold conditions; it can be windy or not; and it can be dusty of not. as well, it may be linked with no precipitation at all or interspersed with light events or, on occasion, torrential precipitation. Knowing which 'type' of meteorological drought can occur is an important step to recognizing the requirements for drought prediction and drought adaptation.

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

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

I doubt whether my specific work has yet affected government policy. it may be that the concept of different types of meteorological drought, with varying features and impacts, may affect some policy decisions in the future.

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

Many new linkages were developed with fellow researchers and with provincial agencies in particular. This allowed me, for example, to meet with several Manitoba government officials concerned with drought and other extremes.

· Whether and how it has enhanced or improved the reliability of predictive methods related to the science;

This work is setting 'requirements' that predictive methods and models must have. Those requirements are very high. Current models, for example, generally do not handle virga very well although this, at least in the 1999-2005 drought, was an important phenomenon. In addition, the concept of cold drought, with its attendant large scale forcing, that is distinct from hot drought, can be utilized in empirical approaches for drought prediction.

· The impact of the project on your own institution (e.g. helped attract new students or personnel);

This research has helped McGill University and the University of Manitoba by attracting students and visibility. Extremes such as drought are very high in the public's eye.

· Whether it has improved or increased the acquisition of funds from other agencies, or led to new partnerships;

This has not happened for my personal research highlighted in this document.

· Any links with international initiatives and the potential impact of these (e.g. profile of Canadian science, influence on international programs);

DRI has allowed for strong linkages with WCRP and GEWEX in particular. DRI was, to some degree, a forerunner in terms of comprehensive research activities examining extremes such as drought. The whole issue of extremes including drought is now very high on the agenda of such international organizations. DRI has contributed significantly to their planning.

· **Any commercial or social application the results may have had or could have;**

There is no commercial application.

· The anticipated impact of the work on Canadians and their well-being;

Drought is a huge issue. As one better understands its fundamental, this can be applied to improved monitoring, prediction and adaptation. Many of the impacts of this work will not translate immediately into improvements but they will contribute to them in the future.

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.

This research is unique; no other comparable study has been carried out before of droughts over Canada and perhaps elsewhere as well.
This research does not directly affect 'tomorrow's' drought. It examines the fundamentals from which vantage point one can develop a strong physically-based scientific understanding of persistent little-precipitation (referred to as drought).

Benefits are already flowing however. Without this research the following would not have occurred.

- The concept of utilizing 'consecutive dry days' as an indication of drought occurrence is insufficient. The recent 1999-2005 drought generally had as many days as normal with precipitation. This is now being recognized by some of the statisticians concerned with extremes and climate.
- The realization that models poorly handle virga and that this is an important shortcoming is being better recognized. ECMWF, for example, is now more fully aware of this issue and recognize their weakness to handle it, a big issue for some droughts.
- The concept that severe drought and severe storms can interact and, in doing so, may actually intensify the storm. This links in with a highly variable climate.

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.

It is easy to list many questions. I will just list three with one encompassing one:

- How are persistent, low precipitation conditions maintained in spite of large scale forcing changes?
- How many chains-of-events are possible for entering and maintaining drought?
- How many chains-of-events are possible for exiting drought?

and:

- To what extent are these issues universal?

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.

Journal Publications:

Carmichael, H., W. Henson and R.E. Stewart, 2010: Extreme precipitation events occurring during the recent drought (1999-2005) over the Canadian Prairies. Atmos. Res. (Submitted)
Evans, E., R.E. Stewart, W. Henson and K. Saunders, 2009: On precipitation and virga over three locations during the 1999-2004 Canadian Prairie drought. Atmos.-Ocean (Conditionally Accepted)
Greene, H., H. Leighton and R.E. Stewart, 2009: Drought and associated cloud fields over the Canadian Prairies. Atmos.-Ocean (Accepted)

Szeto, K, W. Henson, R.E. Stewart and G. Gascon, 2009: The catastrophic June 2002 Prairie rainstorm: an extreme rain event that occurred during an extreme drought. J. Geoph. Res. (To be Submitted)

Presentations (besides the DRI January 2009 workshop, DRI Prediction Sept 2009):

Stewart, R.E., J. Pomeroy and R. Lawford, 2010: The Drought Research Initiative: What has been accomplished. Can. Meteor. Ocean. Soc. Conf., Ottawa.
Stewart, R.E., 2009: Drought and Related Extremes Today and Tomorrow. Manitoba Watersheds Conference, Brandon, Manitoba
Stewart, R.E., 2009: Drought over the Canadian Prairies. Environment Canada, Toronto
Stewart, R.E., 2009: Drought over the Canadian Prairies. Univ. Northern British Columbia, Prince George.
Carmichael, H., W. Henson, and R.E. Stewart, 2009: Extreme precipitation events and the recent drought over the Canadian Prairies. CMOS Congress, Halifax, Nova Scotia

Associated Presentations (based in part on DRI research)

2010 WCRP Extremes Workshop Paris
2010 Extremes presentations at GEWEX Scientific Steering Group meetings New Delhi, Seattle
2009 Research for Disaster Reduction for Extremes workshop Winnipeg
2008 Extremes and Ecosystems Symposium at Fall AGU San Francisco

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?

The radar data used in this study has been archived and has been made available to other 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?

Mainly as DRI Co-Lead, I have had numerous interviews. These have included the Globe and Mail, Winnipeg Free Press and national news agencies.

As well, I (with Barrie Bonsal) updated the Canadian Encyclopaedia entry on drought. I also wrote a 1/2 page section of a new 2nd year university textbook that covers drought. This will almost completely utilize DRI information.

I also was successful in receiving funds for a cross-Canada lecture tour on the issue of drought. A brief summary of the current lecture tour is as follows. It will be completed by March 31, 2011 and additional lectures are expected.

2010:
Sept 21 Simon Fraser University
October 21 University of Alberta
Nov 4 University of Calgary
Nov 5 University of Manitoba

November 17 University of Lethbridge
November 30 University of British Columbia

2011
January 12 University of Winnipeg
January 17 Memorial University
Feb 4 Brandon University
Feb 12 or 13 Manitoba Museum, Winnipeg
early March McGill University
March 11 Institute for Catastrophic Loss Reduction, Toronto

7.0 Training

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.

MSc: Erin Evans: clouds, precipitation, virga (currently: Calgary Air Quality specialist)

MSc: Heather Greene (co-supervised with Henry Leighton): clouds, precipitation, radiation and drought (currently: Meteorologist with Environment Canada, Edmonton)

MSc: Trudy McCormick, (co-supervised with Henry Leighton): Radiation fields over the Canadian Prairies during drought, McGill University. (currently: forecaster training course, Environment Canada)

PDF: William Henson (50% of his time): severe storms associated with drought, McGill University (currently: research associate at McGill University)

Research Associate: Hannah Carmichael (completed now, 75% of her time): severe storms and drought, McGill University (currently: BEd student at St. Mary's University, Nova Scotia)