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: Clouds Radiation and Drought

DRI Investigator: Henry Leighton

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) To understand the processes that contributed to the 1999 – 2004 Canadian Prairie drought it is useful to characterize the atmospheric conditions associated with the drought and to compare them with conditions in non-drought years. In our work we concentrated on comparing cloud conditions during drought with those during periods of normal precipitation. We also wanted to investigate how results of a similar analysis based on model output compared with the observations, the idea being to establish the reliability of the model out output. Simply comparing precipitation output from the model is not sufficient. Even If the precipitation from the model agrees with observations, comparing cloud modelled and observed cloud properties provides an additional assessment of the model. And if the model precipitation does not agree with the observations, understanding how the modelled cloud properties agree or disagree with the observed properties will give insight to possible model deficiencies.

We also wanted to investigate whether it was possible to find a relationship between local aerosol properties and drought or non-drought conditions. One hypothesis is that increased dust during drought might impact cloud properties and hence cloud precipitation efficiency.

b) In the Prairie drought of 1999-2004, the region that experienced the greatest number of months of drought or severe drought was concentrated in central and eastern Alberta and western Saskatchewan. The winter (December – February) and to a lesser extent fall (September – November) were the periods that had the largest proportion of months with below average precipitation.

The length of the 1999 – 2004 drought was too short to identify a relationship between cloud characteristics and precipitation anomaly; so although some attention was placed on the recent drought, the 21 year period from 1984 – 2004 was mainly examined. The cloud properties that might be expected to relate to precipitation are cloud amount, cloud thickness and cloud height, although microphysical properties and below-cloud humidity would also be factors. The cloud fields were obtained from satellite measurements and so are unreliable over high albedo snow-covered surfaces; accordingly this analysis concentrated on the months of May – September. There is a clear trend for months with below average precipitation to have negative cloud anomalies. However, the value of r^2 is small (0.17); very little of the Standardized Precipitation Index (SPI) variation is explained by total cloud amount. The regressions are stronger for the late summer months, particularly in the southern agricultural domain (r^2 = 0.23 – 0.37) where the precipitation measurement network in denser. Subdividing cloud according to cloud height showed that medium and high cloud decreased with decreasing SPI.

Since the combination of cloud amount and cloud optical thickness are likely to be better predictors of precipitation, and because cloud amount values may not be reliable when pixels are only partially cloud-covered, correlations were carried between SPI and albedo anomaly. This resulted in slightly better correlations with corresponding values between 0.27 and 0.40. However, because the correlation between albedo and SPI is restricted to daytime measurements, diurnal differences in cloud fields may also contribute to the differences in the correlations for cloud cover and for albedo.

The analysis conducted in this study utilizes the best known available datasets; nevertheless there are some limitations that need to be recognized. CANGRID data is an interpolated grid from surface observations. In Canada, southern portions of most provinces are well covered, often with numerous stations in a $1^{o}x1^{o}$ area. Data coverage in northern areas, however, is sparse; particularly in northern Saskatchewan and Manitoba. This means that it is possible for a particular region to be represented by an unrepresentative value of precipitation as it is possible for the nearest station to be hundreds of kilometres away and hence provide an unreliable value for the SPI.

The question arises as to why the correlations are not stronger. Uncertainties in the measurements and smoothing of the gridded data may be partly responsible but what is probably more important are the contributions of intense but small sub-grid storms that have a greater impact on the grid-averaged precipitation than they do on the grid-average cloud amount or albedo.

The Canadian Regional Climate Model (CRCM) does a good job of predicting average annual precipitation over the Prairies. The data and model placed annual mean precipitation for the period of 1961 to 2004 at 48.6 cm and 47.9 cm, respectively, but the values of annual precipitation in individual years are only weakly correlated. Similar good agreement between model and observations was obtained for mean summer and winter precipitation. The model also accurately reproduces the average annual cycle of precipitation in the southern portion of the Prairie Provinces, where the data coverage is much denser than in the north or in the mountains. The model reproduced qualitatively the observed geographical distribution of the frequency of dry months for the 1999–2004 drought period with maxima in eastern and central Alberta and a secondary maximum in southern Saskatchewan although the peak frequencies from the model are less than from the observations.

As mentioned above, there is a general increase in mean cloud amount anomaly from negative to positive values with increasing SPI but the variability is large and the correlation weak. Stronger correlations are present when albedo anomaly is

correlated with SPI. Simulations with the CRCM showed similar results, but the monthly mean cloud anomaly was significantly more sensitive to SPI than was found from the observations.
In collaboration with Alexander Trichtchenko and Alexander Radkevitch at the Canada Centre for Remote Sensing we looked at MODIS retrievals of aerosol optical thickness (AOT) to see if we could correlate the AOT with precipitation anomaly but the initial study did not seem at all promising and this initiative was set aside.

Periods of drought tend to be periods of increased frequency and intensity of forest fires which can generate intense aerosol plumes. In a case study we found that the impact of the aerosol downwind from major fires is large enough to have a significant impact on the radiation budget of the region and so should be accounted for in regional climate and hydrological simulations.

c) Our research was divided into two stages. In the first stage, we determined how clouds over the Prairies differ between wet and dry conditions, as characterized by the SPI, on a monthly time scale and a 1°x1° spatial scale over the period from 1984 to 2004. We were interested in cloud amounts, cloud thicknesses, cloud amount by layer, cloud optical thickness, and top-of-the-atmosphere (TOA) albedo. We also used the SPI to characterize the 1999-2004 Prairie drought in terms of the frequency of drought months and the number of consecutive drought months. We compared cloud properties in regions that experienced severe drought during this period to those of clouds formed during non-drought conditions. In the second stage, we compared cloud properties, precipitation and TOA albedo from the CRCM with the results from the first stage.

1.2 Explain how the project milestones and deliverables originally proposed were met.

Our goals and milestones evolved as the research evolved.

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.

We see our main contribution as providing characteristics of drought periods and more importantly relationships between precipitation anomalies and anomalies in cloud characteristics. These characteristics and relationships need to be reproduced by the models that are being used to understand drought.

1.6 Describe how the work of co-investigators was integrated or coordinated.

Ron Stewart collaborated in the supervision of M.Sc. student Heather Greene. I collaborated with Alex Trishchenko (CCRS) and a member of his research group, Alex Radkevich, in investigating the utility of the MODIS aerosol data. Kit SZeto (Environment Canada) provided the CRCM data.

2.0 <u>Impact</u>

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

The first part of or work contributed to the characterization of the drought but more importantly it related precipitation anomalies to observed anomalies in cloud properties. While in itself this may not be very revealing, these relationships do place constraints on models that are being used to simulate and hence improve understanding of the processes and situations that favour sustained drought. In the second part we compared the relationships resulting from observations with those resulting from numerical simulations. The simulations showed a significantly strong relationship between SPI and cloud amount than was present in the observations.

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

The project may indirectly lead to improvements in the ability to predict drought by forcing those developing the simulation models (CRCM specifically) to examine the cloud and precipitation parameterizations.

The project attracted two M.Sc. students both of whom have continued their careers after graduation with the MSC. So there was a direct benefit to McGill and to the broader meteorological community.

The project did not lever funds from other agencies but my circumstances were such that that was not a priority for me.

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 would not have been carried out, it was dependent on CFCAS funding.

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.

I would recommend a more careful look at the cloud and precipitation parameterizations in the CRCM.

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.

a) Journal papers (refereed)

Satellite-derived aerosol radiative forcing from the 2004 British Colombia wildfires. S. Guo and H. Leighton. *Atmosphere-Ocean*, 46, 203-212, 2008.

Drought and associated cloud fields over the Canadian Prairie Provinces

H Greene, HG Leighton, RE Stewart. Accepted for publication in the DRI issue of *Atmosphere-Ocean.*

Contribution to the Theme 1 synthesis paper

b) Theses (external evaluation)

Heather Greene. Drought and associated cloud fields over the Canadian Prairies. M.Sc. thesis, McGill University, 2008

Trudy, McCormack. An evaluation of the Canadian Regional Climate Model simulation of the 1999 to 2004 drought over the Canadian Prairies. M.Sc. thesis, McGill University, 2009.

c) Conference Presentations

McCormack, T+. And H.G. Leighton. Evaluation of the CRCM output during the 1999-2004 Canadian Prairie drought. Presented at the CMOS Congress, Halifax, 2009.
Greene, Heather+, H.G. Leighton and R. Stewart. Analysis of cloud fields during the recent Prairie drought. Presented at the CMOS Congress, Kelowna, 2008.

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 metadata have been provided to the data manager.

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.

2 M.Sc. students. Both are employed by the Federal Government