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: *Soil Moisture Initialization for Numerical Weather Prediction*

DRI Investigator: Kenneth R. Snelgrove

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 of Study**: The objectives of the study revolved around a central theme to explore the impacts of land surface soil moisture on the initialization, continuation and termination of the severe drought that began in 1999. As the project evolved, four project elements were initiated: i) remote sensing of changes in terrestrial moisture using gravity measurements provided by the GRACE (Gravity Recovery and Climate Experiment) satellite, ii) hydrologic modelling of a large area of the Canadian prairie using hydrologic/land surface (water/energy balance) models necessary to transfer atmospheric drought to the land surface moisture changes, iii) coupling of groundwater and land surface models to assess the implications of long term drought on the groundwater system, and most lately iv) assessment of land surface moisture changes on the evolution of the atmospheric system or in other words, the feedback of the land surface on atmosphere. Progress on these research objectives, to a greater or lesser extents, have been achieved with the greatest occurring on the first objective.

b) Scientific Findings &

c) **Work undertaken**:

i) GRACE satellite: Three study areas within Canada were used to compare gravity measurements from GRACE with terrestrial moisture changes over the land surface. These areas included: 1) the Mackenzie River basin owing to the availability of modelling results available from MAGS I & II projects, 2) the Saskatchewan River basin and the adjacent Assiniboine River basin that were impacted by the sever drought that began in 1999, and 3) the Assiniboine Delta Aquifer (ADA) area of south-western Manitoba to explore scale related limitations of gravity measurements. A number of research paper were developed from these explorations that showed that: 1) The GRACE satellite is able to measure changes in land surface moisture in keeping with its original error expectation of 1 cm water equivalent when averaged over GCM grid size areas, 2) the drought that began in 1999 could be observed over the Canadian prairie as a gravitational anomaly and using traditional techniques, an index of large scale drought could be provided, 3) the signal measured by the GRACE satellite is primarily groundwater related and can be disaggregated to reflect local conditions given sufficient

prior measurements. Sitotaw Yirdaw, a PhD graduate from the University of Manitoba, undertook these efforts as part of his thesis work.

ii) Hydrologic Modelling: The original intent of hydrologic modelling in the Canadian prairie was to provide a test bed for coupling groundwater and a land surface models to assess their interaction over large areas using large computational grids. To kick the process off, the VIC (Variable Infiltration Capacity) hydrologic model was selected to help organize data sets and to provide a model inter-comparison with the stand-alone MESH hydrologic/land surface model that is under development. Due to a variety of problems, work never progressed much beyond the implementation of VIC model over the Upper Assiniboine Basin in Saskatchewan. None-the-less, this did allow a number of traditional comparative studies to be made including: i) streamflow fluxes from the basin and ii) storage measurement including geologic weighting lysimeters, developed by Garth van der Kamp, during the period of the drought that started in 1999. A journal article detailing streamflow flux comparison was published and a second outlining storage comparison was reviewed successfully but withdrawn by the authors pending updates. Both articles show good comparison between measured and modelled data during the drought period. Clement Agboma, a PhD graduate from Memorial University, undertook this as part of his thesis work.

iii) Coupling of Groundwater and Land Surface Models: One hypothesis developed early in the DRI program contemplated that a feedback from the land surface to the atmosphere might provide an important forcing during the drought extreme. To detect such signals, it was felt that groundwater would play an important role since it would remain the loan source of available moisture during drought. To test this, an ambitious program of model development and testing was initiated in a collaborative effort with Dr. Allan Woodbury. From this collaboration, a paper outlining the treatment of the lower boundary condition within the CLASS model (Canadian Land Surface Scheme) was developed which permitted interaction between unsaturated and saturated moisture necessary for future coupled model development. This work was primarily the work of a post-doctorial fellow at the University of Manitoba, Youssef Loukili.

In addition to model development, a data rich area in southwestern Manitoba known as the Assiniboine Delta Aquifer (ADA) was identified to serve as a code development test bed for a coupled model. While the area was too small to assess atmospheric impacts, it would allow assessment of simulation quality for a new groundwater/land surface coupled model. To begin the process of data gathering and integration within a modelling framework, an existing coupled code known as ParFlow was employed. Modelling with ParFlow showed that groundwater levels do indeed respond with changes from atmospheric derived drought conditions but that the computational expense of traditional 3-D groundwater codes will have to be simplified significantly to fit within an atmospheric modelling framework. Sitotaw Yirdaw undertook this work as an unpublished portion of his PhD thesis at the University of Manitoba.

iv) Land Surface feedback on Atmospheric Conditions: The final year of DRI coincided with my sabbatical year. I spent this period at the Environment Canada's RPN (Recherche Prévision Numérique) group in Montreal. Much of this period was focused on initializing a new project to determine the impacts of land surface conditions directly on atmospheric simulations. While no meaningful results are available at this point, a climate version of the GEM (Global Environment Model) know as GEM-CLIM will be run to assess the impacts of land surface moisture impacts on the evolution of seasonal forecasts. During this period, two first-year Engineering work-term students (Seth Bennett and Mathew Carter) where employed to make streamflow and adjusted precipitation data sets available within the GEM modelling framework.

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.**

Results from GRACE satellite have led to new research in collaboration with Environment Canada on the role of land surface moisture in seasonal forecasting.

1.6 **Describe the participation of government (federal, provincial or local), university, industry or foreign researchers in the project.**

Manitoba Water Stewardship (Provincial Government) was very helpful in providing water well records and climate station data for the Assiniboine Delta Aquifer (ADA) area. This was the primary data used for ParFlow modelling over the ADA.

Environment Canada provided access to their 3-D global analysis product during the period of the drought over North America. This was the primary tool used for the intercomparison of land surface moisture and the GRACE satellite.

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.

Use of gravity measurements from space to assess the evolution of drought has been the primary contribution of my research to DRI. This allowed the evolution of the drought that began in 1999 to be monitored from space. When averaged over the entire area of the Saskatchewan River Basin (SRB), the change in moisture level was smaller than would be anticipated; only 7 cm of water equivalent. Impacts over the Canadian prairie are very sensitive to even small changes in moisture.

Other initiatives, started during DRI, including coupled groundwater/land surface modelling and land surface feedback to atmospheric models are important initiatives that might be continued in the future.

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

  Collaboration between groundwater and land surface modelling groups was an important component of DRI. This has follow on from the MAGS project where atmospheric and land surface communities worked closely. DRI has expanded this earth system science collaborative to include groundwater researchers.

- **Whether and how it has enhanced or improved the reliability of predictive methods related to the science;**
- **The impact of the project on your own institution (e.g. helped attract new students or personnel);**
- **Whether it has improved or increased the acquisition of funds from other agencies, or led to new partnerships;**

  Work with DRI has resulted in interest from Environment Canada and new collaborations with RPN researchers particularly related to the evolution and initialization of land surface moisture in seasonal prediction.

- **Any links with international initiatives and the potential impact of these (e.g. profile of Canadian science, influence on international programs);**
- **Any commercial or social application the results may have had or could have;**
- **The anticipated impact of the work on Canadians and their well-being;**

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.

(Insert Text)

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.

Significant work has been accomplished in the observation of the drought that began in 1999, including the remote sensing of drought using gravity anomalies used in this project. However, much work remains regarding the prediction of drought events. Development of new modelling tools, involving groundwater redistribution, have been started under DRI but these require significant effort to continue. Such new model parameterizations could then be assessed to determine if they add skill to drought prediction.

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 Articles Published:

Yirdaw, S.Z., Snelgrove, K.R., Seglenieks, F.R., Agboma, C.O. and Soulis, E.D. (2009). *Assessment of the WATCLASS Hydrological Model Result of the Mackenzie*

River Basin Using the GRACE Satellite Total Water Storage Measurement. Hydrologic Processes, DOI: 10.1002/hyp.7450.

Agboma C.O., Yirdaw, S.Z. and Snelgrove, K.R. (2009) *Intercomparison of the Total Storage Deficit Index in two Canadian Prairie Catchments*. Journal of Hydrology, 10.1016/j.jhydrol.2009.06.034

Yirdaw, S.Z., K.R. Snelgrove and C.O. Agboma (2008) *GRACE satellite observations of terrestrial moisture changes for drought characterization in the Canadian Prairie*, Journal of Hydrology, 356 (1), 84-92

Loukili, Y. , A.D. Woodbury and K.R. Snelgrove (2008) SABAE-HW – An enhancement of the water balance prediction in the Canadian Land Surface Scheme. Submitted to Vadose Zone Journal, 7: 865-877.

Journal Articles Accepted but Pending Changes:

Agboma C.O., Snelgrove, K.R., Yirdaw, S.Z. and G. van der Kamp (2009) Moisture Storage Patterns Derived from a Hydrologic Model Validated with Outputs from GRACE and Geological Weighing Lysimeters. Journal of Hydrology.

Journal Articles in Review:

Yirdaw, S.Z., and K.R. Snelgrove, Groundwater Storage from GRACE Over the Assiniboine Delta Aquifer (ADA) of Manitoba. Submitted to DRI Special Issue.

Abstracts, Posters and Confrerence Presentations:

Agboma C.O., Snelgrove, K.R., Lye L.M and Yirdaw, S.Z. (2009): Assessment of the soil moisture patterns over the Canadian Prairie during extended period of dryness. Canadian Society of Civil Engineers Conference (CSCE), St. John's, NL, Canada. May, 2009 (Abstract and poster)

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

Roberts, J., K.R. Snelgrove and M. Organ (2008) *Climate Change Studies for Hydroelectric Utilities*, Eos Transactions. AGU, 89(53), Fall Meeting Supplement, Abstract GC31A-0741.

Yirdaw S.Z. and K.R. Snelgrove (2007) *Groundwater Storage from GRACE Over the Assiniboine Delta Aquifer (ADA) of Manitoba: Early Result*, Canadian Meteorological and Oceanographic Society and Canadian Geophysical Union Joint Meeting. May 28-June 1, 2007. St. John's, NL.

Agboma, C. O. and K.R. Snelgrove (2007) *Application of the VIC Model for Water and Energy Budget Studies in the Upper Assiniboine River Basin*, Canadian Meteorological and Oceanographic Society and Canadain Geophysical Union Joint Meeting. May 28-June 1, 2007. St. John's, NL.

Yirdaw, S.Z.; and Snelgrove, K.R. (2006) *Validation of regional precipitation minus evaporation using a coupled GRACE driven moisture storage and measured basin runoff*. Eos Transactions. AGU, 87(52), Fall Meeting Supplement, Abstract GC41A-1031.

Agboma, C. O. and K.R. Snelgrove (2006) Non-Parametric Approach for Trend Delineation in the Canadian Prairie. Eos Transactions. AGU, 87(52), Fall Meeting Supplement, Abstract GC41A-1034.

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Snelgrove, K.; and Yirdaw-Zeleke, S. (2005) GRACE satellite observations of terrestrial moisture changes and drought measurement in Western Canada. 39th Annual Congress: Sea to Sky. Canadian Meteorological and Oceanographic Society. May 31-June 3, 2005. Vancouver, British Columbia.

Snelgrove, K. R., S. Yirdaw-Zeleke, E.D. Soulis, F.R. Seglenieks (2005) *GRACE (Gravity Recovery and Climate Experiment) Measurements for Drought Monitoring?*, Observational and Modeling Requirements for Predicting Drought on Seasonal to Decadal Time Scales, Adelphi, MD, May 17-19, 2005

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?

Two articles in Memorial University publications:
Luminus Magazine v32, no.2 p.12-13. [Memorial University Alumini Magazine]
Benchmarks Magazine, Winter 2007, p.12 [Faculty of Engineering Alumini Magazine]

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.

Student Name	Degree	Project	Current Position	Period Supervised
Clement Agboma (co-supervised): L. Lye	Ph.D.	Prairie Drought Research	Engineering Consultant (dom)	01/2006 – 09/2010
Sitotwa Yirdaw	Ph.D.	Prairie Drought Research	Engineering Consultant (dom)	07/2004 – 04/2010
Matt Carter (WT1)	B.Eng.	EnvCan-Stream Gauge Data	Student – MUN	04/2010-09/2010
Seth Bennett (WT2)	B.Eng.	EnvCan-Adjusted Precipitation	Student – MUN	01/2010-04/2010