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

2010 DRI Final Report

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

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1.0 <u>Progress</u>

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

The purpose of our research was to enhance the simulation capabilities of the well known Canadian LAnd Surface Scheme (CLASS), through the creation of a new model that will have the capability to simulate groundwater flow. The ultimate goal was to couple a Land Surface Scheme to a saturated groundwater flow model through interactions at the water table level.
In order to achieve our goal, SABAE-HW which is a multilayered version of the CLASS 2.6 was created. It is a one dimensional physically-based model that was adopted from a previous version of CLASS (2.6). The physically based calculations of heat and moisture transfers are adequately extended in the new code to fit the desired refined mesh. The Generalized Minimal Residual GMRES iterative method is used to resolve new soil heat flux terms. We also extended all the procedures treating soil moisture flow and infiltration through layers, as well as those related to water content freezing and thawing, and root volume repartition, and others. Two boundary conditions are considered at the bottom of soil profile in SABAE: water boundary condition and unit gradient boundary condition. The water table lower boundary condition is added to allow eventual coupling with groundwater models. The results of SABAE-HW compared with the results of CLASS, SHAW, HYDRUS-1D and HELP models within the Assiniboine Delta Aquifer using NARR atmospheric data. The results demonstrated the capability of SABAE-HW in predicting reasonable moisture profile and water budget terms. Under warm weather conditions, SABAE-HW and SHAW yield similar water content profiles and bottom drainages. Also, in the freezing/thawing situations, detailed moisture profiles by SABAE-HW are contrasted to both CLASS and SHAW solutions.

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

The first field comparison of SABAE-HW using an extensive ten-year data set from BOREAS (Boreal Ecosystem Atmosphere Study) and BERMS (Boreal Ecosystem Research and

Monitoring Sites) project has been finished. The model is also independently tested and verified with SHAW, an unsaturated zone transport model. SABAE-HW was compared against measured data at OJP site over the period 1997 to 2006. Since the code has been developed for Δt=30min, we had a great source of data to assess the performance of SABAE. The code requires three input files: atmospheric, vegetation, and soil type files. Half-hourly atmospheric inputs include short wave radiation, long wave radiation, precipitation, surface temperature, wind speed, air pressure and specific humidity. Since the vegetation type of the field site is dominated by jack pine, they were classified as a needleaf in the model. Two approaches were adopted for imposing the boundary condition at the bottom of the domain. The first approach was to apply unit gradient boundary to the bottom of the grid. Thus, the total depth of soil column was 3 meters (11 layers). In the second approach, since the water table is near a depth of 7 meters, the soil column was extended to 7 meters (19 layers) to fix the water table boundary condition at the bottom of soil column. In both cases, the two first layers have a thickness of 15cm, with 30cm and 40cm for the rest of layers (Figure 1). Comparing the results of simulations and observed data showed substantial agreement in terms of snow depth and soil temperature (Figures 2 and 3). Snow depth and soil temperature were simulated reasonably well by SABAE with correlation value of 0.96 and 0.98, respectively. However there were some discrepancies for simulated soil temperature in winter. A general agreement was obtained in terms of unfrozen soil moisture results (Figure 4), especially in deeper depths but there were general similarities in observed and simulated soil moisture trends in winter. It was also found that unit gradient boundary runs resulted in increased bias towards overestimation of the soil temperature. Both models showed larger errors with regards to the unit gradient boundary condition at the bottom of soil profile while the coefficients of correlation did not change for SHAW and SABAE model. Thus, a safer and more accurate approach, we believe, is to adopt a first type boundary (i.e. water table) condition at the bottom of the domain. The result of this field testing demonstrated the potential of SABAE-HW as a Canadian model capable of simulating snow depth, snow temperature and soil moisture to high accuracy. A more precise field testing of the model should be conducted later to further validate its application to simulate total and unfrozen soil moisture.

Future development of SABAE-HW will include coupling with nutrient transport equations to control nitrate transport at the field scale and subsequently to be used to assess a variety of BMPs (Best Management Practice) aimed at minimizing nitrate leaching to ground water under actual atmospheric and field conditions.

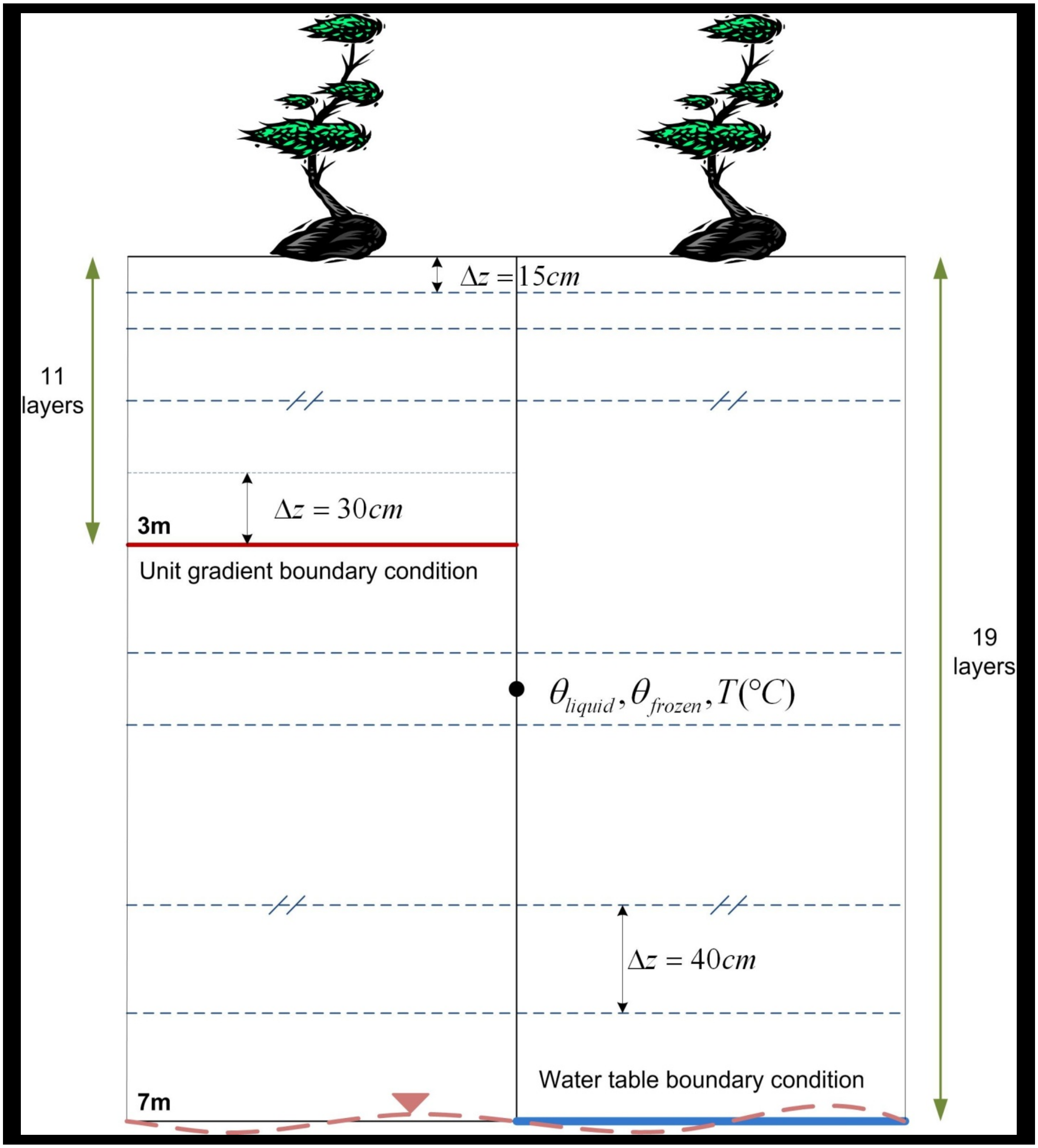

Fig 1. Overview of the lower boundary conditioins in SABAE-HW applied for the OJP site

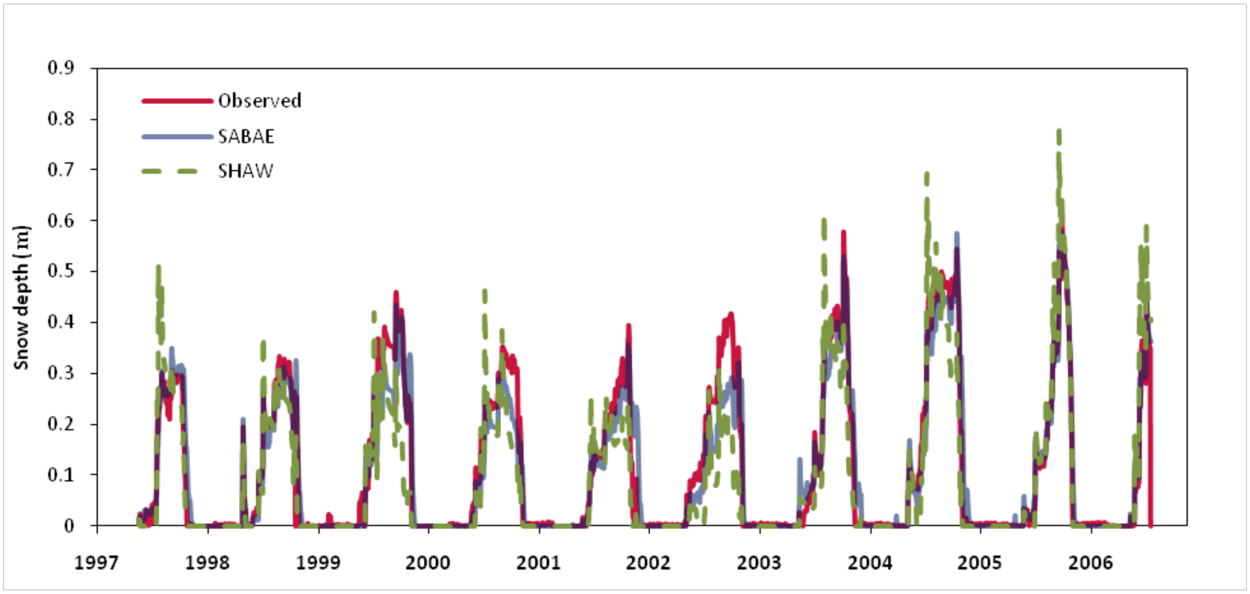

Fig 2. Simulated and measured snow depths Sep. 1997 to Dec. 2006

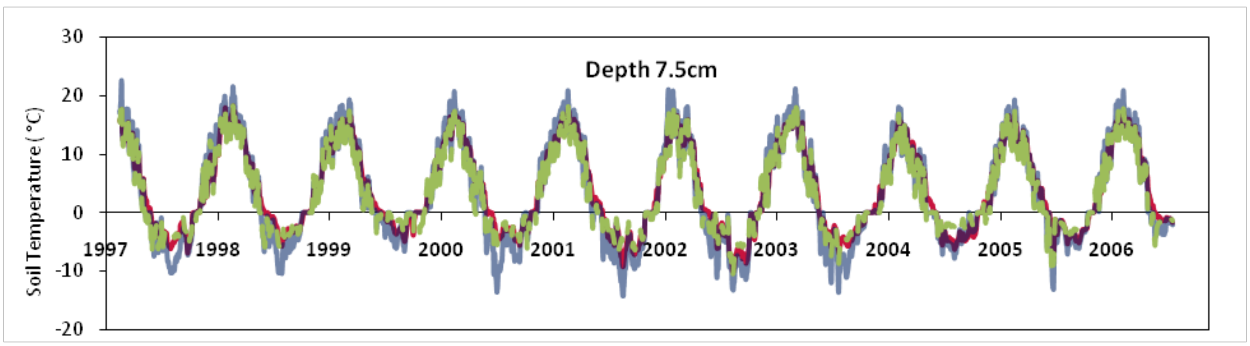

Fig 3. Simulated and measured soil temperatures 7.5cm below the soil surface from Aug.1997 to Dec.2006 (Water boundary condition)

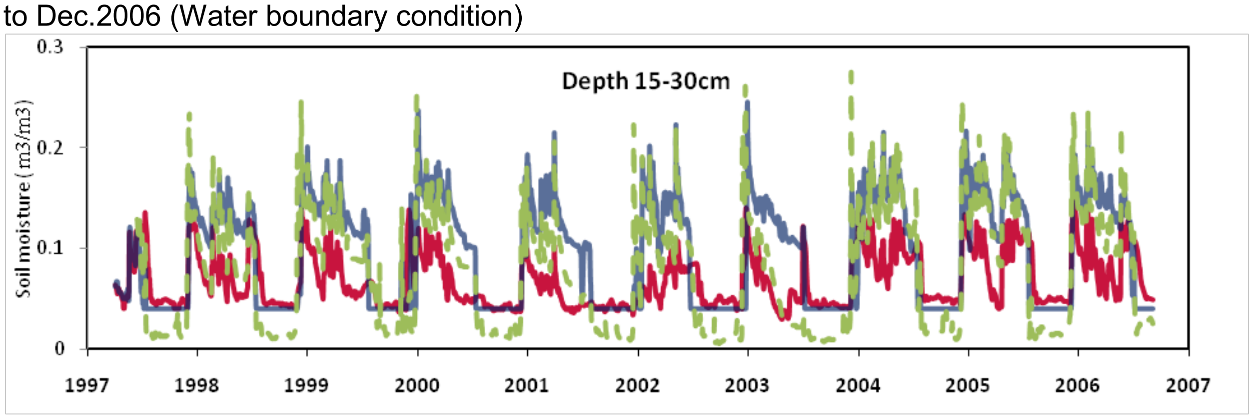

Fig 4. Simulated and measured soil moistures 22.5cm below the soil surface from Aug. 1997 to Dec. 2006 (Water boundary condition)

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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 °C and 1.5°C while the maximum increased between 0.8 °C and 1.5 °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 (in 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.

4.0 Dissemination

4.1 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. Akinrami, Observations of northern latitude ground-surface and surface-air temperatures, Geophys. Res. Lett., 36, 7, doi:10.1029/2009GL037400, 2009.

Hejazi, A. and A.D. Woodbury, Evaluation of SABAE-HW model in simulating snow depth, soil temperature, and soil moisture within the BOREAS field site, Saskatchewan, Accepted pending minor revision, *Atmosphere-Oceans, special edition,* 2011.

Woodbury, A.D., Drought predication and vulnerability of aquifers under climate change, In DRI Legacy Document, R. Lawford editor, 2010.

4.2 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 main version of the land surface scheme, SABAE has been uploaded to the DRI web site.

5.0 Training

1.1 **Quantify student and postdoctoral involvement in the project, indicating the number of: undergraduate, masters, doctoral or PDF's. Also summarize their roles in the project.**

Dr. Lei Wen, (McGill), postdoctoral fellow, funded from DRI
Dr. Youssef Loukili, Research Associate (reduced appointment, DRI funding)
Smrita Joshi, former PhD student (partial DRI funding)
Alireza Hezazi, PhD student (DRI and CWN funded)
Kibreab Assefa, PhD student (CWN funded)