



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

2007 DRI Progress Report

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

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1.0 Progress (beginning January 2007 to end December 3, 2007)

1.1 Overall Objectives and Summary

Our long-term goal is to develop an efficient hydrological and numerical coupling of the Canadian land surface scheme with groundwater flow, and also with the atmosphere through accurate lower boundary conditions. We succeeded in benchmarking of our improved version of the Canadian Land Surface Scheme CLASS, which we refer to as; SABAE-HW (Soil Atmosphere Boundary, Accurate Evaluations of Heat and Water). Inter-comparisons to SHAW, CLASS, HYDRUS-1D and HELP3 ensure the applicability and viability of our code. At this stage, we are continuing numerical tests of SABAE-HW3D which couples the flows in the unsaturated and saturated zones. The coupling strategy was chosen amongst others for efficiency and convergence reasons. We tested the code using synthetic data and comparing to Seep/W results. Our next effort will focus on running SABAE-HW3D over the study site, the Assiniboine Delta Aquifer (ADA), in stand-alone mode. Also, we plan to go ahead in numerical programming towards the ultimate coupling of SABAE-HW3D with the Canadian GCM, in order to allow more accurate exchanges of water and energy fluxes between the atmosphere and the earth surface. Thereby, we believe we are taking the right steps towards our main goal of developing and using the adequate “toolbox” of numerical simulators for drought studies over the Prairies. The overall objective remains to assist the DRI research efforts in trying to understand, assess and quantify the evolution of drought. Also, the inclusion of human practices in each of the model components (agriculture, pumping, wastes, and so on) will definitely allow us to study the influences on climate variability and change.

1.2 Progress

Our developed version of CLASS (SABAE-HW) has two new main features: the soil column depth and layers can be chosen according to any desired application; and the water table boundary condition can be used as well. In addition, the code input and output files are designed in a manner to be clear and practical for any user.

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, 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 that we reviewed.

Another important progress concerns the development of SABAE-HW3D, which actually couples the SABAE-HW 1-D soil columns with a 2-D horizontal groundwater flow model. The generic domain under study is subdivided into soil columns whose surface areas represent GCM grid squares. The depths of columns extend into the saturated zone where a water table lower boundary condition is prescribed. In each column the unsaturated flow is forced by the corresponding meteorological data, and the moisture (liquid and frozen) and temperature profiles are computed by SABAE-HW using a half hour time step. The horizontal flow in the saturated zone is described by a vertically integrated model incorporating a storage term, and discretized using a finite volume scheme operating on the same GCM quadrilateral mesh. Since the saturated flow model affords larger time steps, bottom drainage from the soil columns are summed up and input as cell recharge. Meanwhile, as the water table fluctuates, an individual column's mesh is allowed to deform. This physically-based coupling strategy was selected for its superiority in providing stable and consistent results. In fact, the convergence to steady state situations in both the unsaturated and saturated zones is demonstrated in many validation numerical tests. Moreover, the code was successfully benchmarked against the finite element code Seep/W (Geo-Slope International, 2002) for steady and transient groundwater flows through different soil types.

At the present time, we are applying SABAE-HW3D to the ADA domain using as much observational data as possible. We began this modeling with a coarse grid size 3.5 x 3.5 km and plan to go to 1.5 x 1.5 km. However, we need to fine tune some convergence parameters in order to get over some execution problems related to the stiffness of parameters (mainly the base and permeability). This will likely be a relatively short term problem. A brief list of near-term research targets is given below:

1. Complete successful executions of SABAE-HW3D on the ADA domain using actual atmospheric and soil data over an historic period. Then incorporate progressively other field and hydro-geological data to the model (vegetation cover, detailed soil profiles, detailed forcing data).
2. Complete a parallelized version of SABAE-HW3D code soon, which is necessary for runs over refined grids of the ADA domain (1 km x 1 km or less). We already determined the best communication protocol to be implemented, and we plan to execute the first tests on our 4 processor SUN machine and other HPC computers of the WestGrid platform.
3. For the regional scale representative of the Canadian Prairies, we still plan to use downscaled data over the ADA compiled by the MM5 model.
4. For larger scales, we plan to couple SABAE-HW3D with the Canadian GCM, and we set a coupling strategy for that.

5. Achieve locally and/or with the collaboration of other researchers different site studies using SABAE-HW, SHAW and CLASS models. We believe this would promote the application of our code worldwide as per SHAW.

6. Complete parallel modeling of the ADA using the conventional GMS-MODFLOW package that will incorporate 3-D aspects of the aquifer (Smrita Joshi). This effort will allow for separate inter-comparisons by different researchers on the same area, but with different conceptual models of the recharge to the aquifer and groundwater flow. In this way we can begin to address question on sensitivity of parameters and stability of solutions.

1.2. **What contributions have you made, if any, to the unfunded themes of DRI through support in kind.**

Theme 4: Compare the similarities and differences of the recent drought to previous droughts over this region and those in other regions, in the context of climate variability and change.

Theme 5: Apply our progress to address critical issues of importance to society.

I am currently supported though the Canadian Water Network (CWN). Please note that the entire CWN was renewed for another 7 year period. Our new proposal was entitled “Towards economic and environmental sustainability in agriculture through the implementation of combined beneficial management practices and remedial approaches designed to minimize impacts to water quality” (Dave Rudolph, PI, U. Waterloo) was granted funding as part of the renewal. At this time the actual amount (more than what was requested) is unknown as is each partner’s final amount. It is estimated that this will translate to at least \$30,000 per year for myself for at least 5 years.

1.3 **Describe you plans for research during the coming year and the following year and outline how the expected results will support the deliverables and goals of DRI.**

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2.0 Impact

2.1 **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);**
- **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;**
- **The impact of the project on your own institution;**
- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**
- **Any current (or potential) commercial or social applications, which the results may have;**
- **Links with international initiatives and the potential impact of these;**
- **Anticipated benefits of the work for Canadians.**

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 CLASS 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 recent 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.

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 myself 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. The transport module will account for nitrogen plant uptake, transformations and leaching, as well as for solute exchange between mobile and immobile water. The integrated modeling tools will be used to assess the effectiveness of a variety of BMPs aimed at minimizing nitrate leaching to groundwater under current and evolving atmospheric and field conditions. The simulation results will provide information on the level of risk associated with various nutrient management practices in this type of vulnerable hydrogeologic setting and will support the development of regional nutrient management policies designed to protect groundwater quality in the Canadian Prairies. Although the primary benchmarking simulations for the code will be based on the ADA site, the model will also be considered for application at several of the other research facilities associated with this project (Oxford, Abbotsford) and will be available for application at our partner sites through the WEBS program. The proposed research at the ADA site will also involve a field component that will include the expansion of the database to include relevant solute transport parameters for different soil and vegetation types, and the measurement of additional key hydrologic parameters required for up-scaled regional modelling. Field techniques being developed through the Leaching Risk Indices methods, described below, will be directly implemented for this application.

3.0 Dissemination

3.1 Provide information on 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.

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)