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A Spacially Parallel Implementation of Lake and Land Surface Model Interaction with a Regional Climate Mode

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A SPATIALLY PARALLEL IMPLEMENTATION OF A LAKE AND LAND SURFACE MODEL INTERACTION WITH A REGIONAL CLIMATE MODEL

D. Swayne, V. Sharma, D. Lam, M. MacKay, W. Rouse, W. Schertzer and P. Huang

Abstract

A decade ago, climate change predictions were made by models on coarse spatial resolution where the focus was more on a global scale. Recently, to improve the accuracy, scientists are able to adapt these models to finer spatial scales and to include more detail processes over land and lake surfaces on a regional basis. The objective of this paper is to improve the efficiency of the combined air, land and water components in a regional climate model. This paper shows that for small lakes, which are in the order of millions in Canada, it is possible to treat them as part of the land model module. Furthermore, as each lake acts quite independent of each other, the calculation of a given lake can be carried out simultaneously as the calculation of another lake is being done. If there is a network of computers or a computer with multi-processors deployed for this use, the running time of the regional climate model will be substantially reduced. As an example, we linked a 1-dimensional lake model (DYRESM) to a regional climate model (RCM) in which a land model interface (CLASS) was used as an interface between them. This hybrid model was designed and implemented using a mixture of so-called "serial farm" and "task parallel" approached on the Guelph SHARCNET high performance computer cluser.

MISE EN ŒUVRE PARALLÈLE SPATIALE DE L'INTERACTION D'UN MODÈLE DE LA SURFACE DES TERRES ET DES LACS AVEC UN MODÈLE DU CLIMAT RÉGIONAL

D. Swayne, V. Sharma, D. Lam, M. MacKay, W. Rouse, W. Schertzer et P. Huang

Résumé

Il y a une décennie, les prédictions du changement climatique étaient basées sur des modèles à résolution spatiale grossière qui visaient davantage l'échelle planétaire. Tout récemment, afin d'améliorer la précision, les scientifiques ont été en mesure d'adapter ces modèles à des échelles spatiales plus petites permettant d'entrer dans le détail des processus de surfaces des terres et des lacs sur une base régionale. L'objectif de ce rapport est d'améliorer l'efficacité des composantes eau, air et sol combinées dans un modèle du climat régional. Ce rapport montre que, dans le cas des petits lacs, lesquels sont de l'ordre de plusieurs millions au Canada, il est possible de les inclure dans le module « surface des terres » du modèle. De plus, puisque tous les lacs agissent indépendamment les uns des autres, le calcul pour un lac donné peut être effectué en même temps que celui d'un autre. Si un réseau d'ordinateurs ou un ordinateur multiprocesseurs était installé à ces fins, le temps d'exécution du modèle du climat régional serait considérablement réduit. À titre d'exemple, nous avons relié un modèle hydrodynamique 1D (DYRESM) au modèle du climat régional (MCR) dans lequel un schéma de la surface des terres (CLASS) agissait à titre d'interface entre les deux. Ce modèle hybride a été conçu et mis en œuvre à l'aide d'une combinaison de ce que l'on appelle un « modèle en série » et une « tâche parallèle » déjà abordé dans la grappe d'ordinateurs de calcul de haute performance SHARCNET de Guelph.

NWRI RESEARCH SUMMARY

Plain language title

Speeding up regional climate model prediction with a network of computers

What is the problem and what do sicentists already know about it?

A decade ago, climate change predictions were made by models on coarse spatial resolution where the focus was more on a global scale. Recently, to improve the accuracy, scientists are able to adapt these models to finer spatial scales and to include more detail processes over land surfaces on a regional basis. In the mean time, quite independent of the land model development, scientists have been successful in predicting the heat exchanges over water surfaces from lakes, but the results are yet to be included in the regional climate model.

Why did NWRI do this study?

NWRI scientists have been involved in the development and application of lake models for climate change studies. Recently, they are part of a team of principal investigators from Environment Canada and several universities to conduct a new study to further improve the regional climate model by including a water surface component. The research is funded by the Canadian Foundation for Climate and Atmospheric Sciences.

What were the results?

One of the objectives of this joint study is to improve the efficiency of the combined air, land and water components in a regional climate model. This paper shows that for small lakes, which are in the order of millions in Canada, it is possible to treat them as part of the land model module. Furthermore, as each lake acts quite independent of each other, the calculation of a given lake can be carried out simultaneously as the calculation of another lake is being done. If there is a network of computers or a computer with multi-processors deployed for this use, the running time of the regional climate model will be substantially reduced. This study has received the attention of and funding from the Shared Hierarchical Academic Research Computing Network (SHARCNET) which is a multi-institutional high performance computing (HPC) institute, which promotes excellence in innovative research and accelerates the production of research results which are of benefit to the Canadian economy and the environment.

How will these results be used?

The result on the conceptual design of the interaction between air, land and lake model can be used in the improvement of regional climate model currently developed by Meteorological Service of Canada.

Who were our main partners in the study?

Meteorological Service of Canada; University of Guelph; McMaster University; Université du Québec à Montréal; University of Waterloo; University of Western Australia.

Sommaire des recherches de l'INRE

Titre en langage clair

Accélération des prédictions issues du modèle du climat régional grâce à un réseau d'ordinateurs.

Quel est le problème et que savent les chercheurs à ce sujet?

Il y a une décennie, les prédictions du changement climatique étaient basées sur des modèles à résolution spatiale grossière qui visaient davantage l'échelle planétaire. Tout récemment, afin d'améliorer la précision, les scientifiques ont été en mesure d'adapter ces modèles à des échelles spatiales plus petites permettant d'entrer dans le détail des processus de surfaces des terres sur une base régionale. Entre-temps, indépendamment de l'élaboration du modèle des terres, les scientifiques ont prédit avec succès les échanges de chaleur au-dessus de la surface des lacs; les résultats ne sont cependant pas encore inclus dans le modèle du climat régional.

Pourquoi l'INRE a-t-il effectué cette étude?

Les scientifiques de l'INRE ont participé à l'élaboration et à la mise en application du modèle des lacs pour permettre l'étude du changement climatique. Récemment, ils ont fait partie d'une équipe de chercheurs principaux provenant d'Environnement Canada et de diverses universités afin de mener une nouvelle étude qui permettra d'améliorer considérablement le modèle du climat régional en incluant la surface de l'eau à titre de composante. La recherche est financée par la Fondation canadienne pour les sciences du climat et de l'atmosphère.

Quels sont les résultats?

Un des objectifs de cette étude conjointe est d'améliorer l'efficacité des composantes eau, sol et air combinées dans le modèle du climat régional. Ce rapport montre que, dans le cas des petits lacs, qui totalisent plusieurs millions au Canada, il est possible de les inclure dans le module « surface des terres » du modèle. De plus, puisque tous les lacs agissent indépendamment les uns des autres, le calcul pour un lac donné peut être effectué en même temps que celui d'un autre. Si un réseau d'ordinateurs ou un ordinateur multiprocesseurs était installé à ces fins, le temps d'exécution du modèle du climat régional serait considérablement réduit. Cette étude a retenu l'intérêt et a bénéficié de financements du Shared Hierarchical Academic Research Computing Network (SHARCNET), institut de calcul de haute performance (CHP) multi-institutionnel qui favorise l'excellence dans la recherche innovatrice et accélère la production de résultats de recherche qui soient avantageux pour l'économie canadienne, de même que pour l'environnement.

Comment ces résultats seront-ils utilisés?

Les résultats portant sur la définition du concept d'interaction entre les composantes air, sol et eau peuvent être utilisés dans l'amélioration du modèle du climat régional qui est actuellement élaboré par le Service météorologique du Canada.

Quels étaient nos principaux partenaires dans cette étude?

Service météorologique du Canada (SMC); Université de Guelph; Université McMaster; Université du Québec à Montréal; Université de Waterloo; University of Western Australia.

A Spatially Parallel Implementation of a Lake and Land Surface Model Interaction with a Regional Climate Model

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Abstract: Canada has several of Earth's largest lakes and many small lakes. Heat storage and circulation are greatly affected by lakes. Currently the Canadian Regional climate model does not incorporate a lake component. Therefore, we are linking atmospheric and lake models for such applications as climate prediction and assessing changes in the lake water quality and quantity. We investigate use of highly parallel arrays of clustered processors, available through Canada's SHARCNET. The accuracy of lake, land and atmospheric models depends on grid spacing. Coarser grids adversely affect accuracy. Regional climate model inputs are required subhourly, placing a lower bound on the grid sizes that can be employed. We link a one-dimensional lake model such as the Dynamic Reservoir Model (DYRESM) to a Regional Climate model (RCM) to incorporate the effects of lake on the regional climate. The land model used is the Canadian Land Surface Scheme (CLASS). CLASS and DYRESM are vertical models, with no interaction between horizontally neighboring nodes. CLASS computes heat and moisture fluxes for bare ground (fractional coverage by ground, FG), snow-covered ground (fractional coverage by snow, FSN), ground with canopy (fractional coverage by ground, FC), and ground with both snow and canopy. These fractions are combined to calculate node characteristics. Lake flux values are provided by DYRESM, which are combined with land values according to the fractional lake coverage. Hybrid model is designed and implemented using a mix of both serial farm and task parallel approaches on Guelph SHARCNET high performance computing cluster.

Keywords: CLASS;DYRESM; RCM; Parallel computing.

1. INTRODUCTION

Canada's lakes can have a significant impact on its climate. Also, climate modification will affect lake thermal properties. Canada has several of Earth's largest lakes. There are several million "smaller" lakes, and their overall impact on climate is not well understood.

Regional climate models (RCM) are used in climate change studies. The current Canadian Regional Climate Model (CRCM) uses the Canadian Land Surface Scheme (CLASS) model for computation of heat and moisture fluxes associated with a land mass but is missing a lake component. To enhance the accuracy of the RCM there is definite need of incorporating a lake component in the system (Goyette et al. [2000], Swayne et al. [2003]). These models tend to be computationally intensive. The computational needs grow rapidly with finer grids. Finer grids are highly desired as it leads to increased accuracy of climate change models. The computational needs can be so high that computations may not be reasonably done using serial computers. Here arises the need for parallel computing. Parallel computing can be used to harness the collective computational power of many computer clusters available for the same problem. Depending on the size of the grid and number of processors available in the cluster, a group of nodes in a grid can be represented by individual processors that can be responsible for its computational needs. In this study, a hybrid model to link land (CLASS) and a lake component (DYRESM) with an atmospheric model is developed using parallel computing.

2. BACKGROUND

The Canadian Land Surface Scheme (CLASS) was first developed in the late 1980's using Fortran77 (Verseghy [1991]). This model has been developed and tested over considerable time (Verseghy [2000], Comer et al. [2000]) The model is a vertical one-dimensional model. CLASS involves computation of heat and moisture fluxes for bare ground (fractional coverage by ground, FG), ground covered with snow (fractional coverage by snow, FSN), ground with canopy (fractional coverage by ground, FC) and ground with both snow and canopy, every time step for each grid node (Fig. 1).

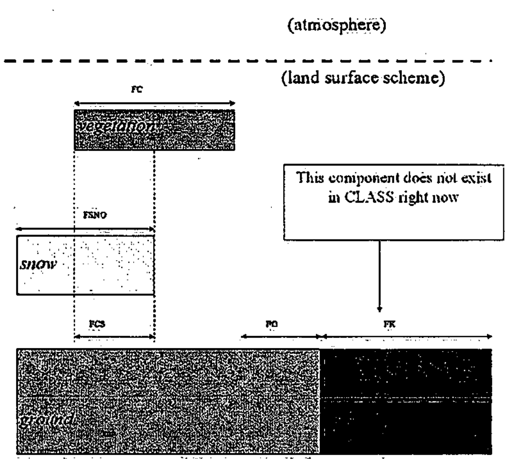

Figure 1. Class structure

The node or grid square representative value is given by weighted average for each iteration. All the required inputs for the model are provided by the regional climatic model (RCM) and CLASS feeds back its results to the RCM for each node, every iteration (Fig. 2).
The following are important facts about CLASS:

CLASS

- Class defines 3 soil layers of fixed thickness 0.10 m, 0.25m and 3.75 m,
- Mean temperature, liquid water content and ice content evolve in time for each layer,
- In soil, heat is transferred by conduction and moisture flux follow Darcy's law, and
- Infiltration of rainwater and phase changes are also accounted.

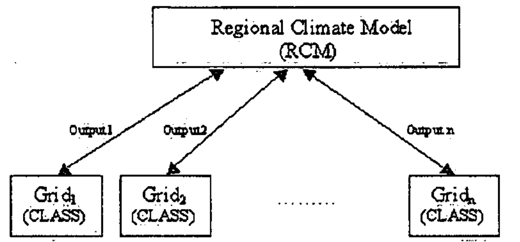

Figure 2. Interaction of CLASS with RCM.

2.1. DYRESM Model

DYRESM (DYnamic REServoir Simulation Model) is a one-dimensional lake thermal model for predicting the vertical distribution of temperature, salinity and density in lakes and reservoirs (Imberger and Patterson [1981]).

DYRESM provides quantifiably verifiable predictions of the thermal characteristics in lakes and reservoirs over time scales ranging from several weeks to tens of years. The model thus provides a means of predicting seasonal and inter- annual variability of such systems as well as sensitivity testing to long-term changes in environmental factors.

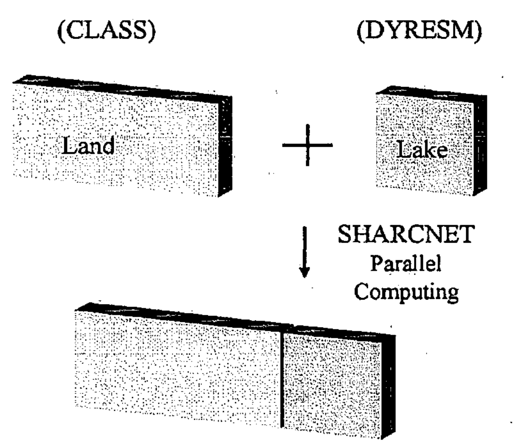

Figure 3. Hybrid model

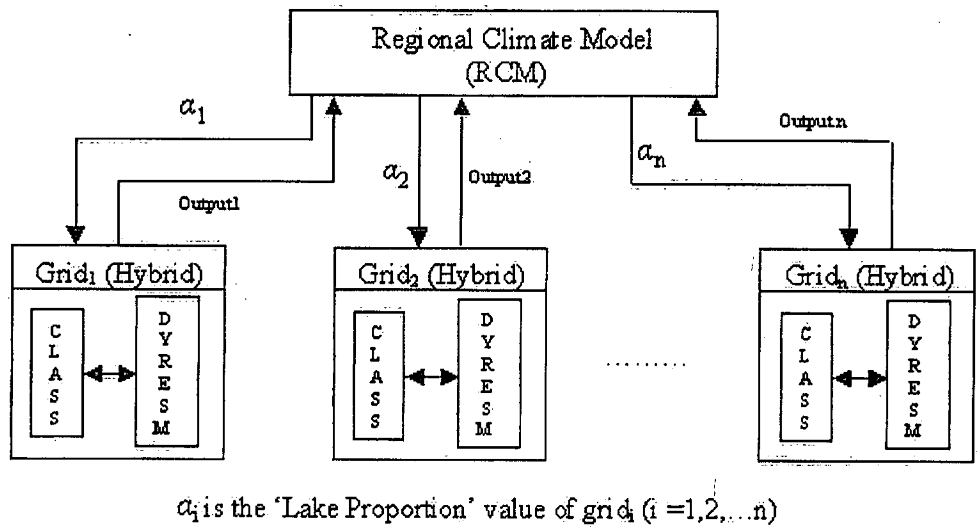

Figure 4. Hybrid model architecture

The following are the inputs for DYRESM:

- Meteorological data,
- Daily lake inflow and outflow data,
- Inflow temperature and salinity, and
- Average 6 hour wind speed.

In this study, an effort is being made to build a hybrid model using CLASS and DYRESM models (Fig. 3).

3. THE MOTIVATION

CLASS is recognized as being able to represent the land grid modes, however, the current structure is inappropriate to represent a grid partially or totally covered by a lake. To combine the DYRESM model into the existing system is being considered as a solution. Meanwhile, a new feature, called 'Lake Proportion', is introduced for every grid cell with both lake and land. The value of this parameter is between 0 and 1. A value of 0 indicates that the grid node is 100% land while a value of 1 represents a 100% lake grid node. Any value between 0 and 1 represents the percentage of the grid surface covered by lake. For instance, if the 'Lake Proportion' value of a certain grid is 0.2 it means that the 20% of the grid surface is covered by lake.

Based on this idea, we can combine the CLASS and DYRESM models in a linear way to construct a new hybrid model (Fig. 4).

Assuming **C**, **D**, and **H** are the vectors of the output data for a specific grid from CLASS, DYRESM, and the new hybrid model respectively. If α is the grid's 'Lake Proportion' value (scalar), then $\mathbf{H} = (1-\alpha)\,\mathbf{C} + \alpha\,\mathbf{D}$

4. PARALLEL HYBRID MODEL

The rationale for running two models in parallel is the time constraint that our design has to meet. All the computations for every grid node for a single iteration (land and lake components) have to be completed much faster than wall clock time of 15 min (for 15 min simulation time steps) for practical applications. As the number of grid cell grows any sequential solution will not be fast enough to meet this time constraint. In addition, there should be minimum change to existing tested code developed over the years. Therefore, solution as used by Soulis et al. [2000], combining two models serially cannot be used

CLASS and DYRESM are two independent models therefore there is no need of communication between the two models before we synchronize them. In order to combine them, we have to synchronize them in a reasonable way. This makes parallel computation an ideal solution to the problem. Parallelism can provide a very simple and efficient mechanism for the purpose.

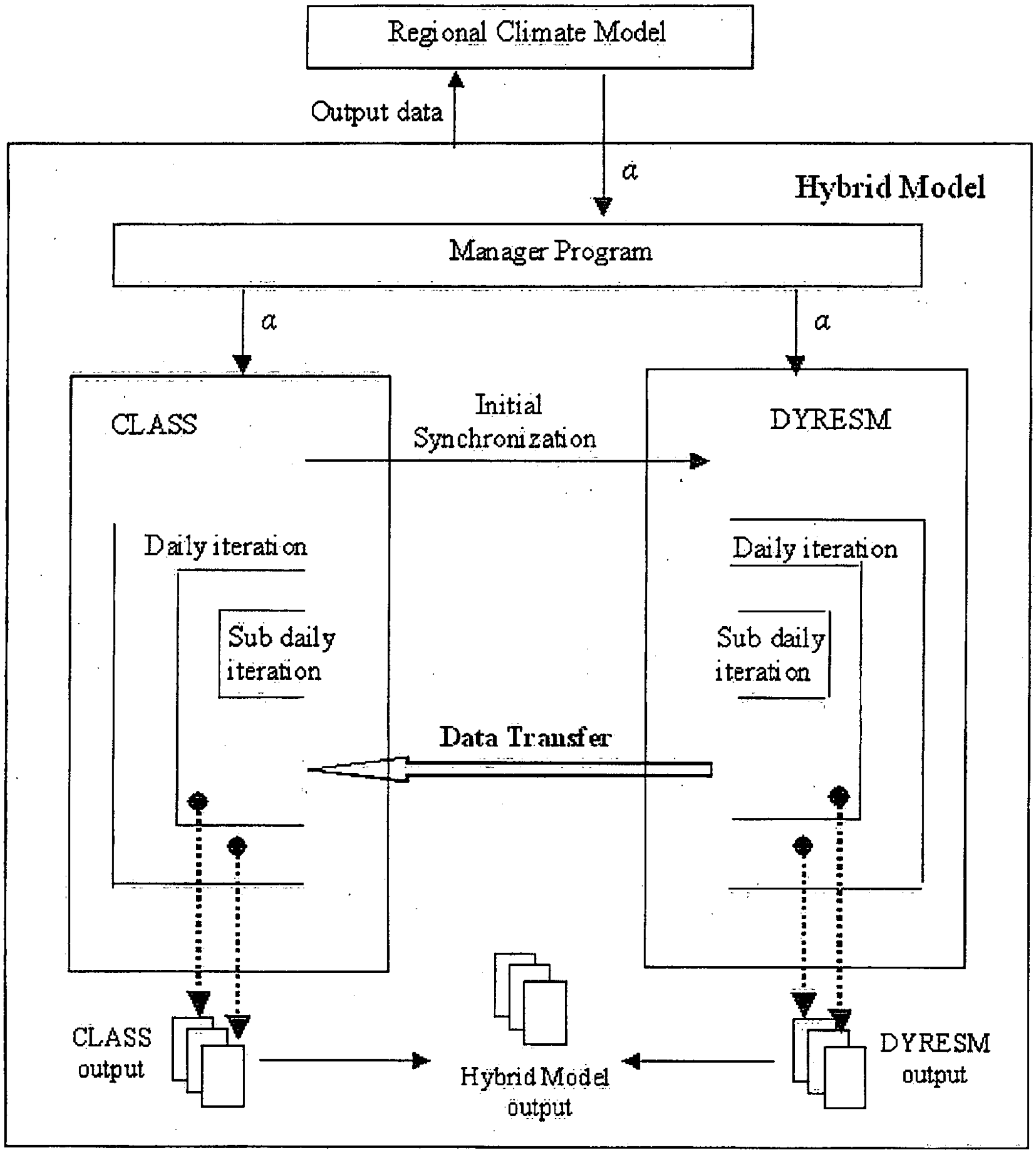

Figure 5. Flow diagram of the hybrid model.

Synchronization of the two models can be done at the end of computations for each iteration of the two models.

4.1. The design

Figure 1, represents a simple representation of CLASS's architecture. As previously mentioned we are incorporating a lake component in this architecture. As a solution, instead of using only the CLASS model in each grid's computation, the new hybrid model is employed to enclose the lake model

(DYRESM) in the system. This structure is shown in Fig. 4.

We have implemented a hybrid model on high performance computing (HPC) Guelph cluster of SHARCNET (The Shared Hierarchical Academic Research Computing Network). The cluster contains 27 Compaq Alpha ES40 nodes with 4 GB memory per node, running Red Hat Linux operating system. Each node has 4, 833 MHz processors.

Fig. 5 illustrates the design of the hybrid model. Every grid node from RCM needs one single hybrid model for its data computation. The design in this study is a mix of *serial farm* and *parallel task* approaches. In *serial farm* design, a copy of a program, which is self-contained and does not have any dependencies of communication with other grid nodes, is run on as many processors available in the cluster. Thus we are running concurrently as many copies of the program as the number of processors available.

Computation of lake (DYRESM) and land (CLASS) components for a single grid node are done using parallel task approach by running the two models concurrently, so that their combined result is the output of grid node. These paired models are farmed out to as many processors available on the cluster, as there is no dependency of the pair on any other grid node, thereby, using *serial farm* approach.

The two independent models, CLASS and DYRESM, run in parallel on the cluster. To accomplish this, two processors are needed, one running copy of CLASS and the other copy of DYRESM. The CLASS (land model) will run on the even numbered processor and the DYRESM (lake model) on the odd number processor.

A manager program acts as an interface to take parameters from RCM and communicate to CLASS and DYRESM. It distributes copies of CLASS to the even number processors, the copies of DYRESM to the odd number processors. CLASS and DYRESM synchronize at end of each iteration by communicating their output to the manager, which computes the combined grid node output based on the fractional coverage of the grid node. This computed value is then available for RCM. This process is continued till the desired time period.

5. CONCLUSIONS

The current Canadian regional climate model does not incorporate a lake component. The presence of some of the largest lakes of the world and more than a million small lakes in Canada makes it imperative that a lake component be included to enhance the accuracy of climate change simulations. In this study, a lake model (DYRESM) is linked with currently used land model (CLASS) using parallel computing to form a hybrid model. This hybrid models can help incorporate the effects of lake in the climate change simulations.

6. ACKNOWLEDGEMENTS

This research is supported by SHARCNET, Canadian Foundation for Climate and Atmospheric Sciences, NSERC, and Environment Canada.

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