Lakes in General Circulation Models

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Overview

The use of General Circulation Models (GCMs) is very well established for studying and predicting possible future climates under the forcing of increased greenhouse gas concentrations. Furthermore, the continuing development and execution of this class of models is being supported by a large number of personnel and much expensive computing hardware at a number of centers throughout the world. In the past, two significant problems accompanied use of this type of model for more regionally-based application in the Great Lakes basin: a coarse spatial resolution and lack of representation of the Great Lakes as part of the model. The use of regionally-nested climate models at finer grid spacing is only a partial solution to these problems. GCMs usually provide full dynamical simulation of the world's oceans, but many, including the current generation of the one developed and run at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), completely ignore the presence of all inland water bodies, except for a highly rudimentary treatment of the Caspian Sea. However, as the spatial resolution of GCMs becomes finer, this deficiency becomes more critical. The insertion of 1-dimensional (vertical diffusion) models of lake thermodynamics coupled with GCMs will result in an added element of realism for the GCMs and will put the simulation of lakes under altered climate within a single fully self-consistent model that is created, maintained, and updated by a large staff, and is run as a priority job on a multi-million dollar computing system.

Proposed Work

Incorporate code for ice formation and ablation into existing 1-D code for lake thermodynamics. Experiment with running simulations including Laurentian Great Lakes, tune parameters, and evaluate need for flux adjustment.

Add other worldwide large inland water bodies and tune them.

Scientific Rationale

The use of general circulation models (GCMs) is a long-established method for predicting the influence of increased greenhouse gases on climate, as well as other perturbations that can force climate. The GCM "industry" has only a limited number of centers that devote large amounts of human and computing resources to the development, execution, and analysis of GCMs. GLERL's sister lab, the Geophysical Fluid Dynamics Laboratory (GFDL), is one of these centers. On the order of 100 people there are involved in the science, computer engineering, and computer operations that make the GFDL GCM run and remain up to date. In addition, they spend on the order of $30 million for their main computing system at each replacement cycle of about 6 years.

The main reason why the usefulness of this effort was less in the past than it might have been for GLERL's purposes is that the spatial resolution achieved by these models was very coarse when considering regional climate. During the time period 1990-2003 or so, gains in computing power have been devoted primarily to making simulation times longer and creating larger ensembles of simulations using the same forcings but different initial conditions. During this time, however, little change was made in the spatial resolution of GCMs. It appears that the tide is beginning to turn. GFDL has gone from using a standard transform grid of 2.5 degrees of longitude and latitude, to using a 1 degree grid spacing, and doing shorter-duration simulations of the atmosphere at only 0.5 degree grid spacing. This latter spacing in the Laurentian Great Lakes region is about 55 km in the N-S direction by 39 km in the E-W direction. This trend will only go toward finer grid spacing in the future. However, these models have mostly ignored the presence of inland water, or at least treated it in only a very rudimentary way.

In addition to running longer simulations with larger ensemble sizes and finer grid spacing, GCMs have gradually added more complexity. Thus they are including more components of the complete climate system. One component that is currently being inserted into many GCMs, and causing a trend toward calling them Earth System Models (ESMs), is the carbon cycle. This will allow for simulating any feedbacks that may by occurring between climate and biota via photosynthesis (both marine and terrestrial).

All of these trends indicate a process of fine-tuning of these models, and in particular the trend toward finer grid spacing makes it more important to include lakes as a component of these models. At least as a first step in this, a simple formulation of lakes seems most appropriate. The most simple is a model with a fixed depth of mixed layer with the appropriate thermal capacity. In older GCMs, a similar formulation was used for oceans, and was called the slab ocean model. Somewhat more complex is a 1-dimensional diffusion formulation, with horizontally distributed grid cells being treated separately from each other. The highest level of complexity would be to use a full 3-dimensional dynamical model of lakes.

The advantage of this approach over the regional climate model approach discussed in the proposal for Dynamical Modeling is that it forms a self-consistent climate simulation system. There is no one-way nesting of a regional model into the already-completed simulation of a global domain. Instead, the lakes are fully interactive with the entire world, rather than with a limited domain that is only receiving, but not giving back, information from its larger context.

The use of the 3-D dynamical model seems excessively complex at this time. The use of the slab model, which effectively has zero dimensions, or the 1-dimensional diffusion model, looks more attractive. These can be used in a tiling approach even if the grid cell of the GCM is not completely covered by water. The additional computational burden presented by these calculations will be very small compared to the full GCM. One drawback of these approaches is the likely need for flux correction, since in reality heat can be transported horizontally in the lakes.

Bruce Wyman and Isaac Held of GFDL have already experimented with a slab model of the Laurentian Great Lakes in the GCM, and have found some deficiencies, mainly excessive duration of ice cover. Additional refinement of this formulation may help, and the 1-d diffusion formulation will also be tried. A major advantage of the 1-d model is that it yields information on the stratification of the lakes and how this may change as a result of climate change.

Use of the term "Laurentian Great Lakes" has been avoided here, because all of these arguments apply to inland water bodies throughout the world. While the Laurentian Great Lakes will be used for the first experiments, followed by other large lakes of the world, it is feasible to include rudimentary formulations of even small lakes, treating them as covering only fractional parts of the GCM's grid cells.

Governmental/Societal Relevance

The societal motives and relevance of this project are very similar to those of the Dynamical Modeling project. The results of greenhouse warming scenarios using more basic methodologies (the Great Lakes Regional Climate Assessment) have been gratefully received by a variety of policy and private interests, but have been marred by using GCMs that ignore the presence of lakes. Many of the same interests would welcome the use of GCMs that include lakes as part of a complete self-consistent system. Those that I am most aware of are the IJC, Wisconsin Sea Grant, Great Lakes United, and National Wildlife Federation. This institutional interest is indicative of the importance of climate change effects on water resources for shippers, riparians, ecological conservation interests, and policymakers. In combination with the use of statistical downscaling techniques, the results of these GCMs will be appropriate for application at regional scales, and will become even more so as time brings further advances in GCM simulation and computing capability.

Relevance to Ecosystem Forecasting

The history of GCMs is long. They were envisioned as one of the original applications of electronic computers, and during the 1950s at the University of Tokyo were calculated using slide rules. However, their usefulness for understanding of climate processes at regional scales is finally now becoming a reality. The coupling of lakes into GCMs offers a fully interactive and self-consistent simulation environment, so that the atmosphere and the lakes fully reflect the changing character of each other, along with the full global climate system. In combination with statistical downscaling techniques, which may be applicable to the lakes themselves in addition to the atmosphere, the resulting output will be useful for driving simulations of various impacts on the Great Lakes basin.