Driving a 3-Dimensional Lake Dynamics Model Using a Global General Circulation Model: A Proof of Concept

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Abstract

The spatial and temporal scales that can be investigated for global and regional aspects of the climate system are beginning to converge. Reducing the number of hand-offs of data among different models in a causal chain leading from anthropogenic greenhouse gases to an end-point impact (lake water levels, fish growth, etc.) reduces the opportunity for conceptual inconsistencies among models ("black boxes") in that chain. In contrast to the more conventional plan of using dynamically downscaled climate model output to drive regional phenomena associated with climate change, we are investigating the use of a 3-dimensional model of the Laurentian Great Lakes, driven directly by output from a general circulation model of climate with a global domain. The Great Lakes version of the Finite Volume Coastal Ocean Model (FVCOM) has been tuned for use on the Great Lakes, and currently has an operational version for short-term prediction. The Geophysical Fluid Dynamics Laboratory Climate Model version 4 (GFDL CM4.0) has been developed at that NOAA lab for multi-decadal projection of climate in the air-land-ocean system. Direct driving of FVCOM by output from GFDL CM4.0 will enable greater consistency of modeling than downsampling layers, and hence better conceptual fidelity among the pieces of the modeling system.

Previous Work

Simple models of vertical mixing of lakes as coupled to atmospheric models by Lofgren (2004) and Goyette et al. (2000) do not have a mechanism to inhibit vertical mixing in response to early initiation of a thermocline. The FLake model (Mironov et al. 2010) uses a canonical set of shape functions for the temperature profile, and is not well suited to lakes with a deep nearly-isothermal hypolimnion below the thermocline. Xiao et al. (2018) used the Weather Research and Forecasting (WRF) model including its lake component, WRF-Lake, which formulates lakes as individual columns with vertical diffusion of heat dependent on wind speed and explicit measures of static stability throughout the water column. General global circulation models (GCMs), generally with a horizontal discretization of about 1 degree in longitude and latitude, are not capable of good resolution of the Great Lakes, but can be set up to have rudimentary interaction with them. Our immediate goal is to create a one-way coupling system for GCMs to drive a model that simulates the hydrodynamics and thermodynamics of the Great Lakes under various GCM scenarios.

FVCOM

The Finite Volume Coastal Ocean Model (FVCOM) is a 3-dimensional hydrodynamic model that can be used for regional simulation of both salt water and fresh water. A Great Lakes version has been developed at GLERL (Anderson et al. 2018). It uses the finite volume form of horizontal discretization of a configurable unstructured grid. Great Lakes applications typically use 11 sigma layers in the vertical. FVCOM has been applied to short-term prediction and is being transitioned in stages to operational use. However, we wish to use it for multi-decadal simulations at time horizons up to a century away.

There has been concern about numerical instability of FVCOM’s dynamical code, and the need to insert artificial diffusion to force stability. This problem has been corrected by Drs. Wang and Fujisaki-Manome, which should lead to stronger and more accurate thermocline features and overall model performance. Another enhancement is aimed at the simulation of ice, and this version is called FVCOM-CICE.

Challenges and Future Plans

All new uses of models have technical difficulties to overcome, including this one. The transfer of data from one model into a set of variables and a format that another model will accept can be a challenge, and a mismatch between the height of data in the native spatial grid of one model and the expected height of input data for another model is one example of an incompatibility that causes difficulty but is not insurmountable. The default inputs of FVCOM-CICE include net heat flux at the surface, which is a direct thermodynamic driver, but may be at odds with turbulent fluxes of latent and sensible heat that would have been calculated directly by FVCOM. We will test and validate FVCOM-CICE in a one-way coupled mode, although the direct input of near surface heat flux will strongly constrain the thermodynamics of the model.

This project is intended to be a long-term collaboration between GLERL and GFDL, with the future incorporation of FVCOM-CICE as a component of future generations of GFDM’s GCMs. This will require much work in software engineering, tuning, and evaluation. After completing this work for the Laurentian Great Lakes of North America, we will extend this to other large lakes worldwide.