Lake Champlain

Primary Investigator: Gary Fahnenstiel - NOAA GLERL
Co-Investigators: Mike McCormick

Overview

GLERL is participating in a large-scale multi-institutional program to study Lake Champlain as mandated by Congress. The research direction is set in cooperation among the three major participants: The Lake Champlain Research Consortium (LCRC), NOAA/GLERL and NOAA/ARL. GLERL’s primary role has been in hydrodynamics research.

Objectives

Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.

Define the primary forcing factors and time and space scales that affect water quality and quantity for selected ocean, coastal, and Great Lakes regions.

Proposed Work

A manuscript pertaining to Lake Champlain hydrodynamics has been submitted and it is based upon recent analyses of surface drifter experiments conducted during the summer months in the years 2003-5. This was the largest and most extensive observation of surface currents ever conducted on Lake Champlain including the Northeast Arm (Inland Sea) of the lake.

In addition, an all inclusive proposal was written with Richard Artz (ARL) to NOAA describing four projects which comprise the Lake Champlain research program. This program was fully funded by NOAA and allows research to build upon the efforts of the recent past. The Lake Champlain Ecosystem Research Program consists of four projects. The projects are:

1. Atmospheric Exchanges of Mercury with Lake Champlain and Their Influence on Rates of Mercury Accumulation in Plankton and Fish.
2. Building a Hydrodynamic Modeling System to Predict Circulation and Thermal Structure in Lake Champlain.
3. Analysis of Historical data Sets and Further Investigations within the Restricted Arm of Lake Champlain.
4. Monitoring Meteorological Conditions on Lake Champlain and a Summary Analysis of Annual Mercury Deposition at Underhill, Vermont.

The hydrodynamic model (POM) is a nonlinear three-dimensional hydrostatic model with embedded turbulence submodel. The original POM employs a terrain-following vertical coordinate. The model was used previously to study internal waves and currents in various coastal environments including the Great Lakes (Beletsky et al., 1997, Schwab and Beletsky, 1998, Beletsky et al., 2003). In this project, we adopted the recently released general coordinate version of POM which allows the use of either sigma-coordinate or z-coordinate, or a blend of both coordinate systems (Mellor et al., 2002). Our expectation is that the new model (POM-Z) will be capable of handling areas with steep bottom topography which present a problem for a typical sigma-coordinate model like original POM.

The existing version of POM for Lake Champlain uses a 500 m grid which can be insufficient for an accurate description of water exchange in narrows. Therefore, we obtained a new 10x10m bathymetric dataset for Lake Champlain and developed a new 200m grid. New grid was successfully tested in short-term 3D simulations of internal seiches using the standard version of POM.

New grid testing continued with July-August 2004 3D barotropic runs using realistic winds. For that purpose, we obtained wind data from the Burlington International Airport (BIA) and generated gridded fields to force the model. Surface currents from a 3D model run were used to drive a 2D particle transport model to predict Lagrangian drifter movements in the lake for about a week starting July 15. During this period, three drifters were deployed in the central part of the lake by Dr. Michael McCormick (NOAA GLERL). While all drifters propagated significant distance northwards, the modeled drifters exhibited primarily eastward movement with significantly lower speeds. This most likely is an indication of the problem with the wind field used in the model. Indeed, the plots of wind measured at BIA showed stronger E-W wind velocity components than N-S components while N-S winds are most likely the preferred directions over the lake due to the air flow channeling by the mountains on the west and east side of the lake. Therefore, we will be looking for the wind data collected over the lake to compare with BIA data and develop approaches for overland/overlake wind speed and direction correction.

The coding for the POM-Z is complete and we began testing and refining the model. The testing is done mostly for short-term wind episodes. In particular, we successfully ran the model for July 2004 using winds observed at BIA and are now in the process of comparing POM-Z results with standard POM results. To test the model further, we will perform the same model run with a 3D baroclinic version using a typical summer vertical thermal structure for model initialization.
Since the retention time for Lake Champlain waters is only about 2 years (Myer and Gruendling, 1979), it is imperative to include river flows in long-term model simulations. We explored data availability for 20 major rivers for modeling in a hindcast mode and determined that both climatological and real-time data are available from USGS for use in future simulations.

For FY08 the results from the model were compared to observations of temperature and currents. Progressive vector diagrams of winds observed at Colchester Reef were compared with observed drifter tracks using 3% wind factor. Results showed that in most cases this empirical model predicts surface current speed in the lake well (McCormick et al, 2008). This finding will help to calibrate 3D model further. Next, surface currents from a hydrodynamic model will be used to drive a particle transport model to predict Lagrangian drifter movements in the lake and compare results with observed drifter tracks. Future work will also include model runs with added surface heatflux to test spring-summer thermocline development, tests with increased vertical resolution, and tests with idealized forcing.

The Lake Champlain program at GLERL has been a continuing program for over 15 years, and there has never been a formal review of the program. In FY08 we planned a review for October 29-30, 2008 in Burlington, Vermont. This review will thoroughly analyze all parts of the program for their scientific accomplishments and relevance to NOAA's mission. The results from this review will guide all future programmatic activities.

Accomplishments

In 2005 several meetings were held to help refocus the Lake Champlain research priorities. A Cooperative Institute for Limnological and Ecological Research proposal was written to cover both the atmospheric and hydrodynamic research being conducted on Lake Champlain under the direction of the research consortium, ARL and GLERL. The Lagrangian data from 2004 have been edited and the subsequent analyses have begun.

The major emphasis for 2004 was conducting hydrodynamic field studies. The field program was successful with fixed moorings deployed in the northeast arm of the lake. In addition, the Lagrangian portion of the field efforts used surface and subsurface (RAFOS) drifters during July and August.

In 2003 9 moorings were deployed in Lake Champlain in June including temperature data loggers, ADCPs and sound sources for deep water RAFOS experiments. Drifter experiments were conducted in Lake Champlain in July. All moorings were recovered and RAFOS experiments completed in August.

Prior to GLERL principle investigator Michael McCormick’s involvement two now retired investigators James Saylor and Gerald Miller served as the GLERL’s Lake Champlain research program leaders.

GLERL initiated a long-term measurement program to study currents and water temperature fluctuations in the deep, main basin of Lake Champlain using funds first provided by the FY1992 Congressional Add-On. The main lake basin measurement program continued intermittently through FY1997. Additional studies of water mass exchanges between the main lake and one of
its major embayments have also been made. In FY1994, the measurement program concentrated on the dynamics of the main lake’s north end, where earlier observations showed high speed bottom currents and bottom sediment resuspension in water as deep as 100 m. In FY 1997, resuspension of bottom sediments in the lake’s shallow south end was investigated. GLERL has used over one-half of the Congressional Add-Ons funding this research to support collaborators.

Lake Champlain is mostly ice covered in winter. Current measurements made during one-winter season (1992-93) revealed relatively quiescent flow conditions. Currents are stronger during the spring and fall periods of isothermal water, but attain their highest speeds during summer and fall when the water is strongly density-stratified. Oriented in a north-south direction, the long, deep, and narrow stratified lake is very sensitive to winds from these directions that funnel through the Champlain Valley. The lowest mode internal seiche of the main lake basin has a period close to 4 days in length during late summer. Wind forcing has considerable energy near the same period. The main basin internal seiches attain very large amplitudes under near-resonant wind forcing, wave heights as large as 40 m have been measured. Large quantities of water, both above and below the thermocline, slosh back and forth along the long axis of the lake. Water current speeds driven by the seiche escalate to high speeds (40 cm/sec near bottom speeds have been measured), sufficient to erode and transport bottom sediments that in many areas are contaminated with toxins.

A major observational study of currents and water mass exchange processes within the Shelburne and Burlington Bay complex was performed from September 1999 to August 2000. A large number of subsurface moorings with attached Acoustic Doppler Current Profilers and thermistor strings were deployed in the Bays and water stage and temperature measuring instruments were placed around the perimeters. Early analyses of the data have shown surface wave oscillations with periods of nearly 30 minutes driving currents into and out of Shelburne Bay and also large water stage oscillations of nearly 3.5 days in period driving mass exchanges. The shorter period waves have been modeled as a surface standing wave confined to Shelburne Bay and the longer period wave is apparently a barotropic response of Shelburne bay to the baroclinic 1st-mode longitudinal internal seiche of Lake Champlain. A diurnal thermocline oscillation within the bay complex was also observed but has not been linked with a corresponding lake surface oscillation.
A Lagrangian drifters (RAFOS) program commenced within the main lake basin near the end of the Shelburne Bay field program (late May - early June 2000). USGS, the Lintilhac Foundation, Middlebury College, and NOAA shared funding for this program. The principle investigators were Tom Manley (Middlebury College) and Jean-Claude Gascard (Laboratoire D’Oceanologie Dynamique et de Climatologie, Paris, France). The intent of the study was to determine the feasibility of tracking subsurface drifters using acoustic transponders and receivers throughout the basin to measure Lagrangian currents. Using acoustic travel times between a fixed array of moored stations and freely floating subsurface floats, the floats positions were computed by triangulation.

Scientific Rationale

Studies of the hydrodynamics have been underway on Lake Champlain since 1992 and is being expanded to include novel lagrangian experiments, modeling and lower food web work. Fahnenstiel will assume responsibilities for any lower food web work and its potential application to water quality modeling. The major emphasis for 2007 will be spent conducting hydrodynamic field studies and applying a fully three-dimensional hydrodynamic model to existing data sets.

The mean circulation patterns of Lake Champlain have been very difficult to obtain using long-term Eulerian measurement techniques due to the large oscillatory motions created by the internal seiche. A research program recently began on Lake Champlain involving the use of deep-ocean neutrally-buoyant free-drifter technology known as RAFOS. Research participants include: Dr. Jean Claude Gascard (Laboratoire D’Oceanologie Dynamique et de Climatologie
LODYC, Paris), Dr. Ken Hunkins (Columbia University), Dr. Tom Manley (Middlebury College) and NOAA GLERL.

The program consists of two field efforts. First, an acoustic propagation phase that would provide results as to whether or not Lake Champlain would be capable of supporting an acoustic net that could be used for tracking underwater drifters. The use of underwater acoustics is essential to the success of the program in that the underwater drifters have to be able to detect and verify the encoded signals emitted by the various sound sources moored at precise locations within the lake. The location of the drifter over time can then be determined using triangulation techniques knowing the distances from the various sound sources. The experiments are designed around the standard deep-ocean equipment operating at 1560 HZ. The drifers are of a new design “Lake Champlain Profiler” based upon the WHOI “SOLO” float and built by Pierre Tillier (Seascan, Falmouth Massachusetts) A couple of these RAFOS drifters would be tested in a free drifting period to fully evaluate the experimental design. Once the testing phase is completed the second phase will consist of large-scale experiments involving fixed current meter moorings, RAFOS drifters and GLERL satellite-tracked surface drifters. The RAFOS and surface drifters will allow us to estimate the lagrangian flow field in both the surface mixed layer and in the hypolimnion as well.

A Great Lakes version of the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) has recently been applied to Lake Champlain to study internal seiche dynamics in the lake. In the past, the model was used to study internal Kelvin waves in Lake Michigan (Beletsky et al., 1997). The model was applied to idealized and realistic bathymetry cases in order to understand factors influencing dynamics of internal surges and seiches. Model results for idealized bathymetry were compared with observations of currents and temperature in Lake Champlain collected by GLERL scientists during 1993-1998 (Beletsky et al., 2000) and showed qualitative match. Unfortunately, the model did not produce physically realistic results in the case of realistic bathymetry because of excessive numerical noise. The modeling efforts will be to extend the previous modeling results to do a more systematic study of the effects of bathymetry and stratification in Lake Champlain using another version of the Princeton Ocean Model, which uses different vertical coordinate system and maybe less prone to numerical noise. These efforts should also be considered as a first step in preparation for seasonal simulations of circulation and thermal structure in Lake Champlain.

**Governmental/Societal Relevance**

Lake Champlain research is mandated by a congressional add-on to NOAA’s budget.

**Relevance to Ecosystem Forecasting**

The National Academy of Sciences, the President’s Committee of Advisors on Science and Technology, and the National Science Board all call for improvements in the capability of ecosystem forecasts. There is a need to improve the understanding of how environmental drivers change community structure and ecosystem function. More research is critical to understand patterns of ecosystem resilience at a variety of temporal and spatial interaction scales.
The potential major benefits of ecosystem forecasts are: (1) improving decisions to sustain ecosystem productivity and lessening the impacts from extreme natural events and human activities; (2) bringing scientists and resource managers together to solve resource management problems; (3) focusing scientific research and monitoring priorities to reduce uncertainties in ecological forecasts; and (4) to forecast recovery rates to increase effectiveness of ecosystem restoration projects. The various efforts of the research being conducted on Lake Champlain are geared towards improving the capability and reliability of ecosystem forecasting.

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