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MODELING THERMAL STRUCTURE, CIRCULATION AND ICE IN LAKE ERIE

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Abstract

Winter circulation and thermal structure in Lake Erie is studied with a three-dimensional coupled Great Lakes Ice-circulation Model (GLIM) during 1979-1980 and 2010-2011. The hydrodynamic model has 20 vertical levels and a uniform horizontal grid size of 2 km. The model uses time-dependent wind stress and heat flux forcing at the surface which are calculated from the hourly meteorological observations obtained from National Weather Service land stations and NOAA buoys. The model reproduces several month long ice periods in both winters with maximum ice thicknesses up to 45 cm in 1979-1980. The model is validated with hourly temperature and current measurements at several moorings that were deployed in central basin of Lake Erie during both winters and additionally with ice concentration and thickness measurements in 2010-2011.

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1. Introduction

The Laurentian Great Lakes are located between 41 and 49^o N and are at least partially covered with ice from December until April. Normal peak ice cover ranges from 24% for Lake Ontario to is 90% for Lake Erie (Assel, 2003). The spatial progression of ice on Lake Erie is from the shallow west basin (mean depth 7 m) in late December to the deeper central (mean depth 19 m) and eastern (mean depth 24 m) basins in January. By the end of January, Lake Erie reaches it maximal ice cover and retains this cover through February. The overall objective of this study is to develop a basic understanding of Lake Erie (and other Great Lakes) winter hydrodynamics, including circulation, evolution of thermal structure, ice cover and heat exchange with atmosphere. Our specific objectives are to: Determine ice concentration and thickness, thermal structure, circulation patterns in Lake Erie, and related inter-annual variability by means of lake-wide ice, temperature, and current observations and a specially developed coupled ice-lake model; Test modeled ice concentration, thickness and drift, water temperature and circulation using field observations; Determine the impact of lake ice on surface heat and momentum fluxes, lake thermal structure and circulation.

2. Data and Methods

Modeling activities are currently focused on the 1979-1980 and 2010-2011 periods. During the 1979-1980 period temperature and current measurements were made at 31 moorings deployed by NOAA/GLERL and Environment Canada mostly in central basin of Lake Erie. Observations were made at two depths at most moorings: at 10 m and near the bottom. Vertical resolution increased dramatically in more recent measurements, especially those of currents. In particular, the 7 current profilers, 4 ice profilers and 37 temperature sensors were deployed in Lake Erie in October 2010 and retrieved in May 2011. The second year deployment with the same number of instruments but covering a wider area took place during September 2011-May 2012.

Circulation and thermal structure in Lake Erie is studied with a three-dimensional coupled Great Lakes Ice-circulation Model (GLIM) (Wang at al 2010). The hydrodynamic model has 20 vertical levels and a uniform horizontal grid size of 2 km. The model uses time-dependent wind stress and heat flux forcing at the surface which are calculated from the hourly meteorological observations obtained from National Weather Service land stations and meteorological buoys. The model uses a cold start in January 1979 and runs through the end of December 1980, and then again for the 2010-2011 period.

3. Results

The model predicted about 5-month long ice period for 1979-1980 winter with maximum ice thickness up to 45 cm. This is a much thicker ice than the one model predicts (and observations confirm) for the more recent period when warmer winters produce ice only 10-20 cm thick (Wang et al, 2010). Although the model started producing ice at the right time (in December of 1979) its spatial coverage increased faster than in observations in January. The model results matched observations well during the period of maximum ice cover in February-mid-March (over-predicting observations by just about 5%) but ice melt was delayed by about two weeks in the model.

Modeled summer temperatures at 10 m depth qualitatively matched observations but were colder than observed temperatures at 25 m indicating shallower thermocline, most likely due to insufficient vertical mixing. Comparison with water temperature observations in fall and winter showed that modeled temperatures were colder by about 1^{o} C in December which led to earlier ice formation and thus heavier ice cover in the model than in observations potentially indicating problems with heat fluxes calculations.

Comparison of model results with observations during the 2010-2011 period showed the same issue: excessive cooling in the fall and winter leading to extended periods of ice cover in the model. The result of excessive ice production was also seen in weakening of modeled lake circulation as opposed to the observed one. The most likely reason for excessive cooling in the model is deficiencies in interpolation of over-land stations data (air temperature first of all) in late fall-winter when meteorological buoys are retrieved and no overwater observations are available. It is therefore likely that interpolated over-lake air temperature is colder than it should be. Therefore, an adjustment of empirical coefficients in the over-land over-water interpolation method (Beletsky and Schwab, 2001) may be needed to alleviate this problem.

Acknowledgments

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