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INTERANNUAL VARIABILITY OF WINTER CIRCULATION AND ICE IN LAKE ERIE

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Abstract

Winter circulation in the Laurentian Great Lakes is less known than summer circulation and impacts of ice on lake circulation are poorly understood. Lake Erie is at least partially covered with ice from December until April, and its normal peak ice cover is about 90%. To study thermal structure, circulation, and ice thickness, 7 current profilers, 4 ice profilers and 37 temperature sensors were deployed in Lake Erie in October 2010 - May 2011, and again in September 2011 - May 2012. Wind speed observations were obtained from National Weather Service and Environment Canada meteorological stations. Significant interannual variability in the extent of ice cover was observed during the two field years, and that allowed us to study the impact of ice on thermal structure and circulation in Lake Erie.

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1. Introduction

Winter circulation in the Laurentian Great Lakes is less known than summer circulation and impacts of ice on circulation are poorly understood. The Laurentian Great Lakes are located between 41 and 49^{o} N and are at least partially covered with ice from December until April. Comparable in size with the White Sea, Baltic Sea, and the Gulf of St.Lawrence, the Great Lakes are smaller in size than most of Arctic and sub-Arctic seas with seasonal ice cover (Bering Sea, Sea of Okhotsk, or Hudson Bay), but are large enough to exhibit ice drift caused by the prevailing winds and related spatial heterogeneity in ice concentration and thickness. Normal peak ice cover ranges from 24% for Lake Ontario to 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 (Bolsenga and Herdendorf, 1993). By the end of January, Lake Erie reaches it maximal ice cover and retains this cover through February.

2. Data and Methods

To study thermal structure, circulation, and ice thickness, 7 current profilers (4 ADCP and 3 AWAC with ice profiling capability), 4 ASL SWIP ice profilers and 37 temperature sensors were deployed on two transects in central Lake Erie in October 2010 - May 2011. Ice velocity measurements were conducted at 4 ADCP moorings as well. The second year deployment with the same number of instruments but covering a wider area (one of the transects was moved eastward by about 50 km) took place during September 2011-May 2012. Satellite observations of lake surface temperature ice concentration were available about twice a week. Wind speed observations were obtained from National Weather Service and Environment Canada meteorological stations.

3. Results

While winter of 2010-2011 was colder than average (Assel et al, 2013), the winter of 2011-2012 was anomalously warm. Thus, on January 1, 2012 observed lake temperature was by about 5-7 ^{o} C warmer than during the same time in 2011. At most moorings water temperature dropped to zero only by late February 2012, and the deepest central basin location at never reached temperature of freezing. As a result, while annual maximum ice cover peaked at 96% in 2010-2011, it reached only 14% in 2011-2012 and ice formed primarily in the shallow western basin, only occasionally drifting to the area with moorings. Significant interannual variability in the extent of ice cover observed during the two field years provided use with an opportunity to study the impact of ice on thermal structure and circulation in Lake Erie.

The impact of ice on lake currents was not very pronounced overall. Thus, for months with the similar wind speed (February 2011 versus January 2012), monthly averages of 10-min current speed showed only slightly elevated values in ice-free 2012 winter versus icy 2011 winter. This is most likely because ice concentration in the central basin never reached 100% and ice thickness was less than 50 cm on most occasions. At the same time, observations showed very strong temporal variability of ice thickness during periods of highest ice concentration (90% and above), with ice thickness reaching 1 and even 2 m on some occasions. This emphasizes importance of dynamical processes in short-term ice thicknesses variations that needs to be studied further.

Ice velocities were on the order of 20 cm/s but reaching 40 cm/s during strong wind events. Monthly ice drift and circulation patterns during January-March (period of highest ice concentration in Lake Erie) were cyclonic in 2011 (with exception of February when ice drift and circulation were anticyclonic), with current speeds of about 5 cm/s. On the contrary, circulation in 2012 was anticyclonic during all months, but with much weaker monthly currents. This is attributed to a stronger directional variability of 2012 currents. Currents were relatively uniform with depth in both years.

Acknowledgments

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