Time Series Measurements of Ice Thickness in Lake Erie

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Abstract

Time series measurements of ice thickness were made at 6 moorings located in the central basin of Lake Erie during the winter of 2010-2011. ASL shallow water ice profilers (SWIPS) units were deployed at 4 stations and Nortek AWACS profilers equipped with ice measurement software were deployed at 3 stations. At one station both a SWIPs and an AWACS unit were deployed. Ice formation began in the central basin in early January of 2011 and the entire basin was ice-covered by the end of the month. Ice cover continued until the end of the March but was not continuous at any of the stations. There was a pronounced thaw in mid-February when the ice cover all but vanished. The ice was not shore-fast and ice thicknesses varied widely at all of the stations over periods of minutes to hours. Maximum thicknesses reached over 4 m in some instances. There is little correlation of the thicknesses between the stations or between the two instruments co-located at one station. The extreme variability of the measurements makes it difficult to determine a meaningful daily ice thickness.

Introduction

The presence of wide-spread ice cover on the Great Lakes significantly influences lake-effect storms, regional weather, the hydrological cycle, water levels, temperature, and the circulation of the lakes. Knowledge of the growth and decay rates of ice are also needed for models of the thermal cycle of the lakes. This study describes initial results of *in situ* time-series measurements of ice formation and thickness made during the winter of 2010-2011 as part of a joint NSF-NOAA program to measure and model ice growth and its effects in Lake Erie.

Ice in the Great Lakes is first year ice. It usually begins to form in the Great Lakes in December and January and reaches maximum extent in February or early March. Seasonal variation is the dominant phenomenon, and there is significant inter-annual variability in the amount of ice cover. Except in small embayments (the inner parts of Saginaw Bay and Green Bay, for example), the majority of ice on the Great Lakes is pack ice, which is not attached to the shore. The pack ice cover can be very transitory during the winter, particularly in the mid-lake areas, where lake heat storage, air temperature, and wind can move, compact, and alter the concentration and thickness of the ice cover

In Lake Erie the spatial progression of ice formation is from the shallow west basin in late December to the deeper central and eastern basins in January. In the central basin, new ice forms on the northern shore first. Lake Erie reaches it maximal ice cover by the end of January and retains this cover through February. While providing the greatest probability of extensive ice cover, this period also often features large variability in ice concentration.

Measurements

Instrumented moorings were deployed at 7 locations in the central basin of Lake Erie in the fall of 2010 and retrieved in the spring of 2011 (Fig. 1). Different combinations of sensors were deployed on two separate moorings at each station. At stations 1-4, an ASL SWIPS ice profiler and water temperature sensors were mounted at either end of a 100 m ground line that was anchored with a concrete weight at both ends. A separate mooring contained either an RDI adcp (at stations 1-3) or a Nortek AWAC current profiler. At stations 5-7 a bottom–resting tripod was on one mooring, and the temperature sensors and either an RDI adcp (at station 7) or a Nortek AWAC profiler were on the second mooring. Previous experience in Lake Erie in 1979-1980 showed that ice thicknesses could reach up to 10 m during the spring (G. Miller, personal communication), so no sensors were located closer than 10 m from the water surface.

The SWIPS profilers were mounted on a mooring 2-3 meters above the bottom (mab) supported by subsurface floats. These profilers emit a single vertical acoustic beam at 546 kHz to measure the range to the bottom of any ice present. The instruments can be programmed to sample in up to three different configurations during a single deployment. During the deployments described here the instruments were all configured to sample in burst mode (to measure waves) from the deployment date until December 12, and then from May 1 until they were retrieved. These observations are not described here. Between December 12 and May 1 the instruments were configured to measure ice thickness by making range measurements each second, and measurements of water pressure, water temperature, pitch, and roll every 10 seconds.

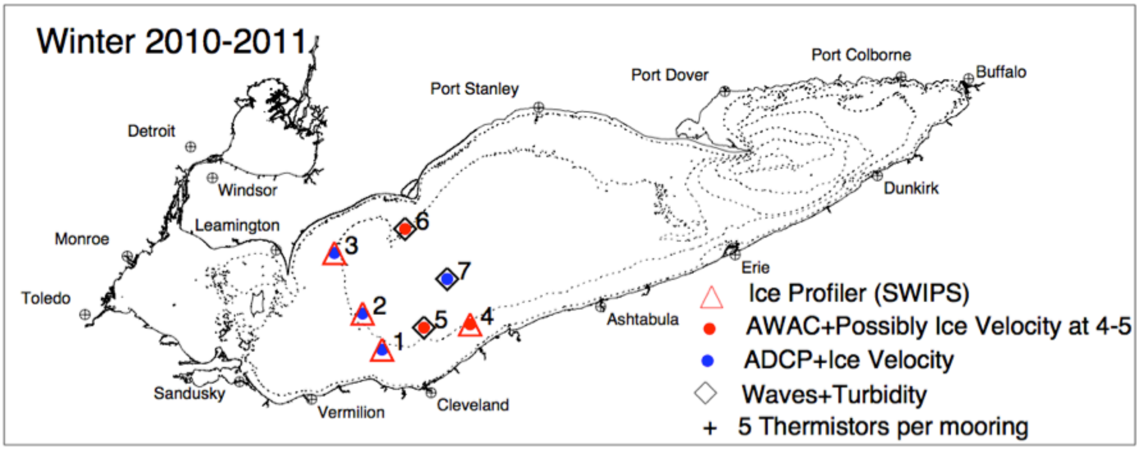

Figure 1. Mooring locations.

At stations 4, 5, and 6 upward-looking Nortek AWAC profilers were deployed at 0.5 mab. Currents were sampled in 1 m bins for 5 minutes every 30 minutes. These units also have a vertical acoustic beam to measure the range to the bottom of any ice present. Burst observations of the range, ice velocity, and pressure were made at 1 Hz for 1024 observations every hour. All burst measurements were recorded. Single point measurements of water temperature, pitch, roll, and instrument heading were made every 30 minutes.

The RDI adcps were also mounted 0.5 mab, and measured currents in 1 m bins every 10 minutes. All of the RDI adcps were also equipped with RDI's ice-tracking software to track the velocity of any ice present. All of these adcps also measured water temperature and three of them (all except that one at station 7) measured water pressure. Both temperature and pressure (as well as the instrument pitch, roll and heading) are single point observations made every 10 minutes.

Temperature measurements were made at multiple heights at each station every 10 minutes with Seabird 39 and Onset U20 sensors. Paroscientific pressure sensors were used to record water depth at 2 Hz for 2048 samples every hour at stations 5, 6, and 7. Water transparency was measured with 0.25 m path length Sea Tech transmissometers located approximately 0.90 mab. These sensors sampled hourly for one minute at 0.5 Hz.

Hourly observations of air temperature, air pressure, wind speed, and wind direction were obtained from National Weather Service Stations located at Cleveland, Fairport Harbor, and Marblehead, the NBDC station located South Bass Island, and Environment Canada stations located at Rondeau, and Southeast Shoals (Fig. 1).

MODIS images of the ice cover in the lake were obtained from NOAA's Coastwatch program. Although cloud cover masks the lake surface for much of the observation period, clear images of the central basin were obtained about once per week.

Calculations

The theory for calculating the ice thickness from *in situ* observations is straight forward. Measurements of the range from the instrument to the bottom of the ice are subtracted from the total pressure measured by a pressure sensor and the difference is the thickness of the ice. In practice the procedure is considerably more complicated since corrections for atmospheric pressure, instrument tilt (which affects range measurements), and changes in the speed of sound (which is affected by water temperature and salinity and affects the range measurements) all need to be included in the calculations. For the ASL ice profilers the manufacturer has written a library of Matlab subroutines to aid in the processing; their use is documented in the IPS Processing Toolbox Users Guide (2011). The process is an iterative one, and one of the keys is to identify periods when there is no ice cover and use those measurements to correct the other measurements. Fortunately there were numerous such episodes at each station during the deployments described here. ASL states that the minimum ice thickness that can be measured is 0.05 m. For these deployments, the process produced a time series of ice thickness measurements at one second intervals. These were averaged over 10 minute intervals prior to computing hourly and daily averages.

The procedure used to calculate the ice thickness from the Nortek AWAC data is similar but varies slightly because of the sampling differences. The Nortek procedures are documented in Lohrmann et al. (2010) and Magnell et al. (2010). Because the AWAC measurements were made in 17 minute bursts each hour, rather than continuously, the half-second data were averaged into hourly burst averages. These were then combined to produce daily averages.

Results

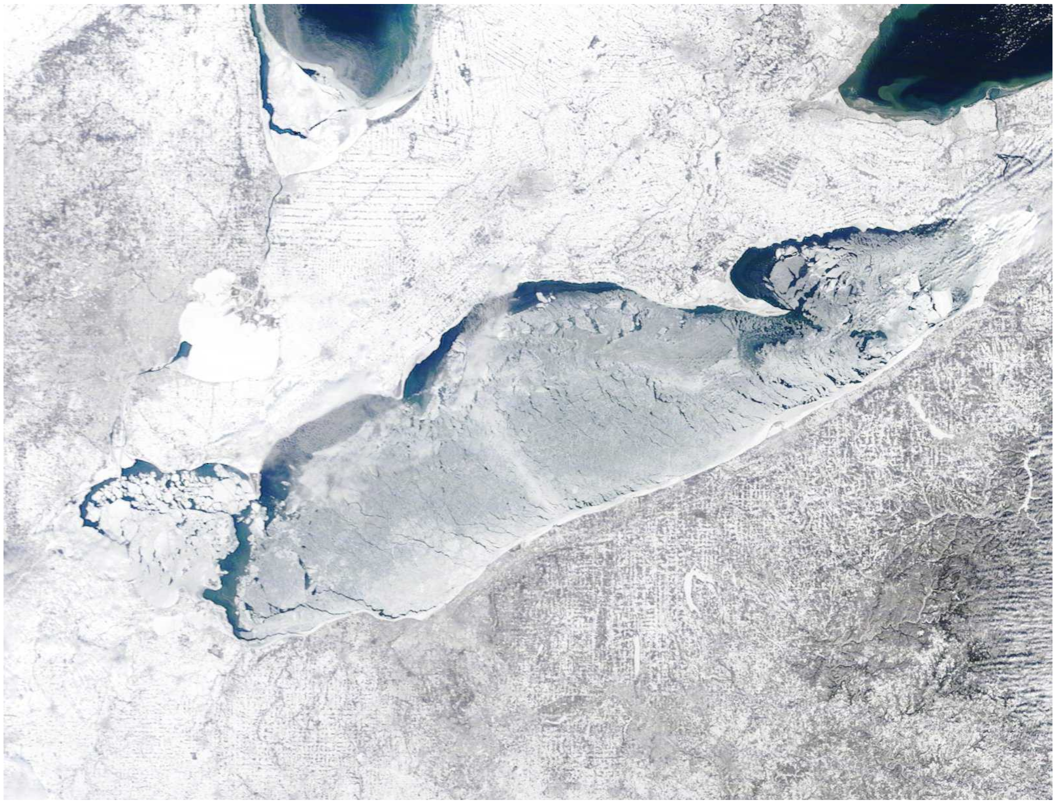

Figure 2. MODIS image taken on February 3, 2011 (day 399).

MODIS images show that ice began to form in the central basin in late December and that the coverage was virtually complete by late January. The cover is not continuous however, as evidenced by the cracks between the floes (Fig. 2). Ice cover remained over the entire observation area through early February, then decreased until about February 22. Ice cover increased again later in the month and in early March before it decreased again as the spring thaw began. After March 12 little or no ice is observed in the deployment area. We limit our discussion in the rest of the paper to the period between December 26, 2010 and March 16, 2011 (when counted consecutively, these are Julian days 360-440).

Meteorological observations (Fig. 3) show that beginning in mid-January the air temperatures were generally below freezing for about a month until early February. They then increased above freezing until about February 20, decrease below freezing until about March 1, and then increased again until the end of the ice cover period. These changes in air temperature agree quite well with the observed changes in ice cover. The met data also show that the air pressures were essentially the same over the entire deployment area, and that the wind speeds frequently exceeded 10 m s^{-1}.

Significant wave heights at station 7 exceeded 1 m numerous times. However the data show no instances of large waves between either mid-January to mid-February or between late February to mid-March even though wind speeds were just as high as during the periods when large waves did occur. Water temperatures were essentially isothermal at all stations and reach 0° C from mid-January until mid-February. They rise briefly and then decrease in late February but do not reach 0° C again. These data are all consistent with the satellite observations of ice cover that show increasing ice cover from early January to mid-February, a brief (about 10 days) warming when ice cover decreased, a second episode of ice formation in late February, and the final melting of the ice beginning in early March.

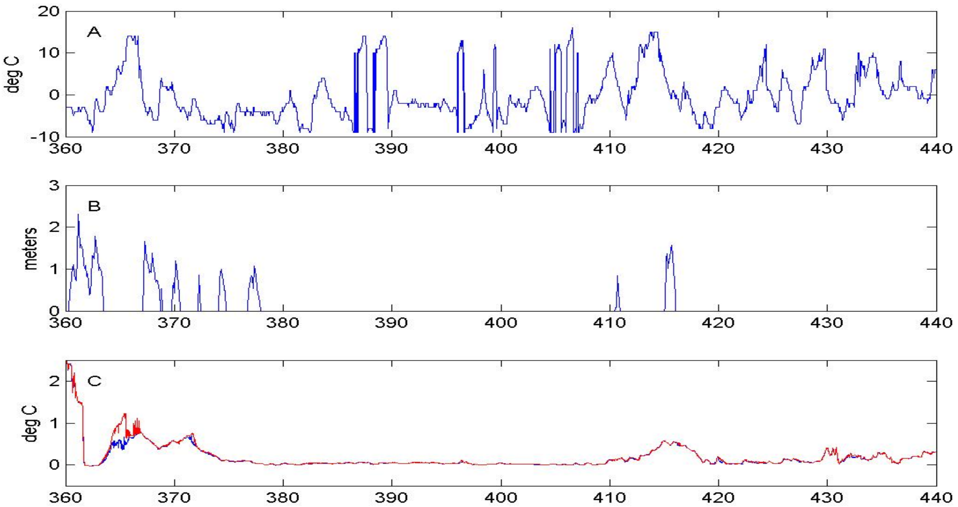

Figure 3. A: Air temperatures at Cleveland. B: Significant wave height at station 7. C: Water temperatures at station 1 measured 1 mab (blue) and 8 mab (red). For reference, day 360 is December 26, 370 is January 5, 380 is January 15, 390 is January 25, 400 is February 4, 410 is February 14, 420 is February 24, 430 is March 6, and 440 is March 16.

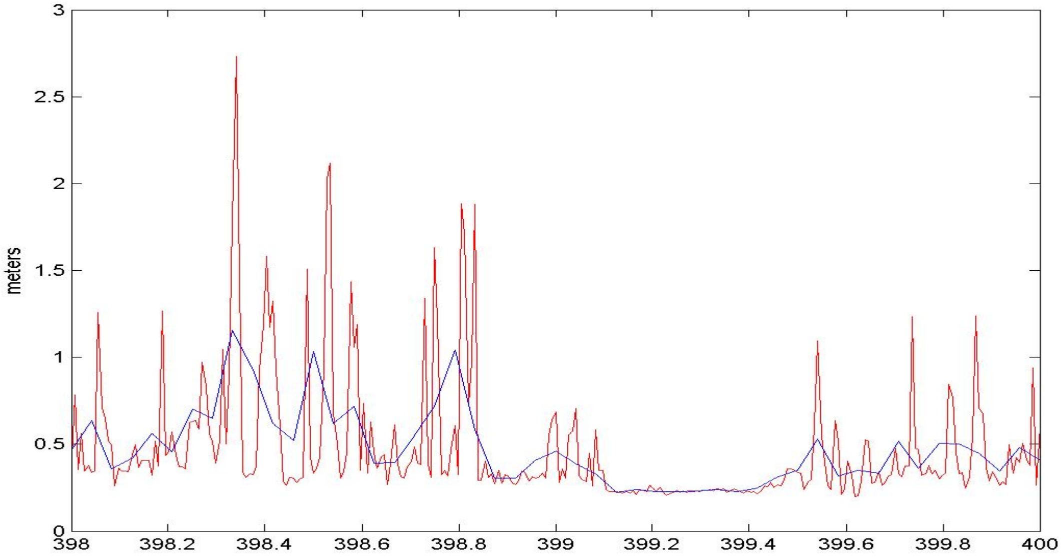

Figure 4. Hourly (blue) and 10 minute (red) averaged ice thickness measured at station 1 on February 2 and February 3. The MODIS image in Fig. 2 was taken on February 3 at1600.

Figure 4 shows that the measured ice thickness can vary considerably over very short time periods and that even hourly averages may underestimate the thickness by a considerable amount. This variablity is caused in part by the movement of the ice past the station, and makes the interpretation of the data much more difficult.

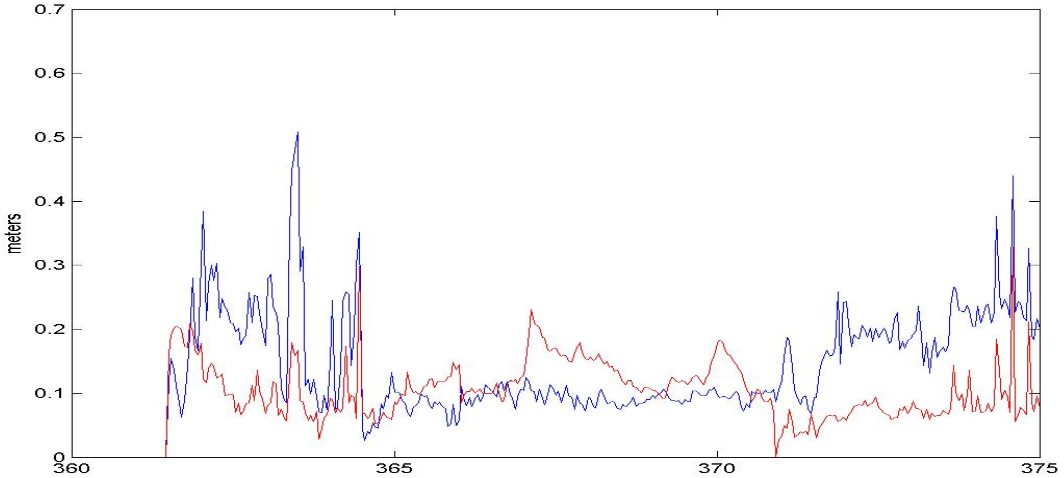

Fig. 5. Hourly ice thicknesses at station 1 from December 26 (day 360) until January 10 (day 375). Blue line is average thickness, red line is standard deviation.

Figure 5 shows that ice is first observed at station 1 on day 362. This is also the first day when the water temperature is zero degrees (Fig. 3), but the large thicknesses may mean that this ice was formed in the western basin and then carried by the currents to this site. The first ice formed at the site may be that formed beginning on day 365. Note that the standard deviations are frequently greater than the mean (hourly averages are shown in the figure). The maximum resolution of the instruments is 0.05 m, so the measured thickness on days 365-370 are very close to the instrument limits.

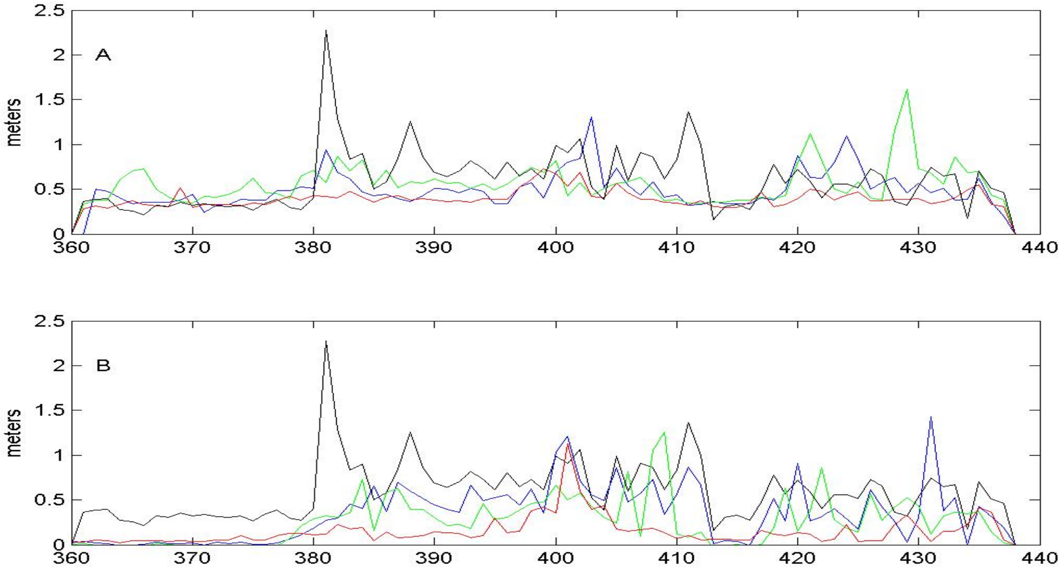

Figure 6. Daily average ice thicknesses. A: SWIPS measurements at station 1 (blue), station 2 (green), station 3 (red) and station 4 (black). B: AWACS measurements (station 4 (blue), station 5 (green), station 6 (red), and SWIPS measurements at station 4 (black).

Daily average ice thicknesses at all of the stations are shown in Figure 6. The data vary considerably, both with time and between stations. The daily averages frequently exceed 1 m, and exceed 2.5 m at station 4. These high values almost have to be the result of ridges in the ice. The effects of the mid-February thaw (days 415-425) can be seen at all stations.

Figure 7 compares the daily ice thicknesses measured at station 4 by the SWIPS and the AWAC sensors. There appears to fairly good agreement most of the days although the SWIPS measurements tend to be larger than the AWAC results. However there are instances where the thickness measured by one of the sensors is much larger than that measured by the other. The sensors were located about 100m apart, so this may explain some of the discrepancy.

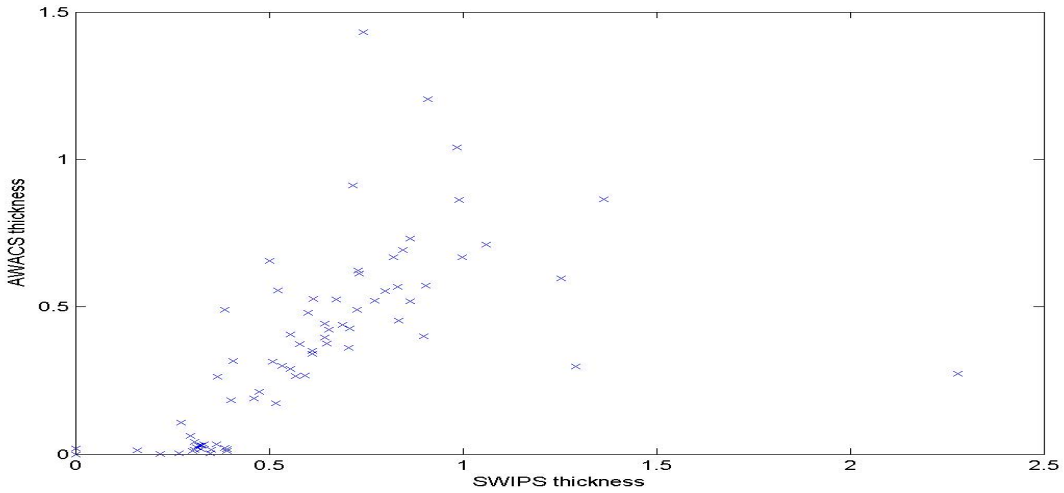

Figure 7. Daily ice thicknesses measured at station 4 by SWIPS and AWAC sensors.

Conclusions

The findings reported here are not yet complete, but it is clear that ice thicknesses in the lake vary considerably both with time and location. There is considerable short-term variability in the data, so it must be averaged over at least 10 minutes in order to make any sense of it, but even 10 minute and 60 minute averages can differ considerably. Estimates of the thickness by two different sensors appear to be in reasonable agreement most of the time, but differ considerably at other times. The differences between these measurements and the ice thicknesses calculated by the National Ice Center(not shown here) also show considerable differences. The high variability in the measurements makes it difficult to determine a single meaningful thickness; most likely the thickness to be used will depend upon the purpose for which it is needed. For heat budgets, for instance, the most common thickness as determined by a histogram, may be more useful than the average.

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