Real-Time Measurements of Ice Draft and Velocity in the St. Lawrence River

R.A.J. Chave, D.D. Lemon and D. B. Fissel
ASL Environmental Sciences Inc
1986 Mills Rd
Sydney B.C. V8L 5Y3 Canada
asl@aslenv.com

Lise Dupuis and Stéphane Dumont
Canadian Coast Guard
Québec Region
Department of Fisheries and Oceans

Abstract - The Canadian Coast Guard monitors winter ice conditions in the St. Lawrence River as part of its responsibilities to prevent and break ice jams in order to minimize the risks of flooding and maintain safe navigation conditions on the St. Lawrence River throughout the winter months. Near real-time information about the coverage, thickness and motion of the ice cover in the navigation channel are required to coordinate icebreaking for maintaining the shipping route, and to prevent and identify ice jams as they develop. Aerial and satellite surveillance provides ice coverage data, but not thickness. This paper describes a test installation in the St. Lawrence that provides real-time ice thickness, ice motion, current velocity and meteorological data from a remote site. The IPS (Ice Profiling Sonar) and ADCP Data Display System (IADDS) consists of two submerged instruments (IPS and ADCP), connected by cable to a nearby lighthouse that is equipped with a computer, weather station, appropriate display software and data transmission capability to shore and the Fisheries and Oceans Department's network. The principles and operation of the IPS and the use of an ADCP to measure ice velocity are described. The IPS and ADCP are installed at 13m depth in the navigation channel in Lac St. Pierre in the St. Lawrence River. Real-time data from the instruments and the weather station are collected at the lighthouse site, and then formatted and transmitted to the Coast Guard headquarters in Quebec City, approximately 200 km away. Web-compatible graphs of the data are then produced for display on the Coast Guard Intranet. The structure of the control, data transmission and storage software is described, and examples are given of the data and its use for managing navigation and detecting ice jams. The results of on-site validation measurements made in the winter of 2002-2003 are also described.

I. INTRODUCTION

The St. Lawrence River downstream from Montréal is infested with ice during the winter season, from about December to March. Congestion of floating ice (frazil and/or brash) can block commercial navigation and cause flooding of the adjacent properties. The Canadian Coast Guard (CCG) has long monitored ice conditions in the St. Lawrence River's navigation channel (Fig. 1) as a part of its responsibilities for maintaining safe navigation and controlling floods. The main sources of information have been ice charts and Radarsat images provided by the Canadian Ice Service (Environment Canada), and observations collected by navigators.

Following the severe ice jam that took place in February 1993, the CCG began investigations to improve its capability to monitor, in real time, ice and environmental conditions in the critical areas of the river subject to ice congestion. The objective was to provide tools to identify, in a timely and efficient manner, the appropriate operational measures to prevent and/or break ice jams, taking into account prevailing ice and environmental conditions. After a few years of effort, the St. Lawrence Ice Management System (SLIMS) was born. This system collects camera and radar images, ice boom loads and weather data at several key sites. All this is routed to a main server through the Department of Fisheries and Oceans (DFO) network and made available on an intranet web site. The cameras and radar can also be remotely accessed to allow ice monitoring in real time.

Even if cameras and radars can provide information on ice coverage and motion, they cannot provide *quantitative data*, like ice thickness and velocity, which are essential to detect and quantify ice congestion. This is why an experimental project was started in 1999 to evaluate the ability of two instruments to quantify ice characteristics: IPS (Ice Profiling Sonar) and ADCP (Acoustic Doppler Current Profiler). This project, performed in collaboration with Laval University, revealed that the ADCP and IPS instruments could provide accurate and reliable data on ice conditions.

In order to make this quantitative data available to ice managers in near real-time, in 2003, the CCG installed a permanent system at Courbe 1, in Lake St. Pierre (Fig 2), and developed software for data acquisition, transmission and processing, in collaboration with ASL Environmental Sciences Inc.

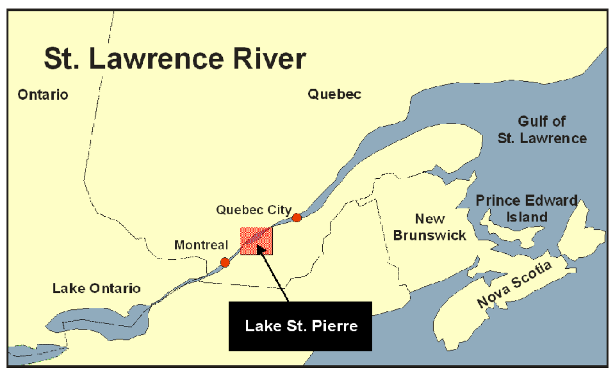

Fig. 1 St. Lawrence River Navigational Channel

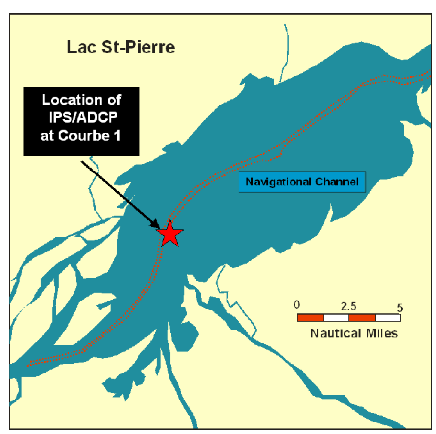

Fig. 2 Courbe 1 Location in Lake St. Pierre

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II. INSTRUMENTATION

The ASL-IPS instrument is an upward-looking ice profiling sonar which provides high quality ice thickness data [2]. It was originally designed by the Institute of Ocean Sciences, Sidney, BC, and after further development is now being manufactured by ASL Environmental Sciences [3]. The ice thickness or, more properly, ice draft, is determined from the return travel time of an acoustic pulse (420 kHz; 1.8° beam at -3 dB) reflected from the underside of the ice. The ping rate is usually once per second (1 Hz). The narrow beam results in a "footprint" of approximately 0.4 m for the ranges used in this study. A pressure sensor (Paroscientific Digiquartz), incorporated within each IPS, is used to measure water levels. The IPS instrument samples acoustic range, and hence ice drafts, at one second intervals.

Acoustic Doppler Current Profiler (ADCP) technology employs the Doppler effect, using the frequency shift in the back-scattered returns from moving scatterers in the water column, to measure the velocity of the water relative to the instrument. The reflected signal from the underside of the ice can be similarly used to determine the ice velocity [4,5]. For this project a 600 Khz RDI Sentinel Workhorse ADCP, complete with the "bottom tracking" feature was used.

From the combination of the ice velocity measurements with the time series measurements of ice drafts, the horizontal distance between ice draft samples can be computed in order to provide measurements of ice draft as a function of horizontal distance. This function has not yet been implemented in the present version of IADDS where ice drafts are plotted as a function of time.

III. ST. LAWRENCE RIVER INSTALLATION

Lake St. Pierre refers to the St. Lawrence River's widening between Sorel and Trois-Rivières. It constitutes the upstream part of the river's estuary. The water depth is shallow, except in the navigation channel, where it is maintained to a minimum 11.3 m below chart datum. Because of the lower water velocity and the presence of curves in the channel, this area is more subject to ice congestion than other sections in the river.

Courbe 1 is one of the SLIMS stations. A remotely controlled camera, installed in the nearby lighthouse, has been monitoring ice conditions in this area since 1999. From 1999 to 2003, the CCG and Laval University collaborated in testing two instruments (IPS and ADCP) submerged at this site in order to measure floating ice characteristics. The installation was made permanent in 2003.

Fig. 3 IPS and ADCP Units

The IPS and ADCP are installed on a platform (see Figs. 3 and 4) positioned in about 13 m of water, on the bottom of the navigation channel (see Fig. 5). They are connected to the nearby lighthouse with two cables that power the instruments and send up data to a local PC, which stores it on the hard drive. Every 30 minutes or so, data files are sent by radio link to the shore, where they are transferred by high-speed internet link to the CCG base in Québec City (about 200 km away).

The Courbe 1 lighthouse is also equipped with a weather station that measures temperature and atmospheric pressure. These data are also stored on the local PC, and then transferred to the CCG base, in the same manner as IPS and ADCP data.

The PC at Courbe 1 runs a number of applications that retrieve the data from the instrumentation and store them locally on the hard drive:

- WinRiver, developed by RD Instruments of San Diego, California, logs ADCP data.
- IpsRealTime, developed by ASL, retrieves the data from the IPS unit and converts it to engineering units.
- PC208, developed by Campbell Scientific, logs atmospheric data from a CR-10 data logger.
- SIG_FTP, developed by the CCG for the specific needs of the SLIMS, transfers data to a server at the CCG Base, via the DFO network. The application scans user specified directories and files on the local PC, at a specified interval of time, and transfers new files if they are not currently being written by one of the instrument applications. IPS and ADCP data files are size limited by IpsRealTime and WinRiver, whereas atmospheric data are retrieved at a specified interval of time by PC208.

Fig. 4 Instruments on Platform

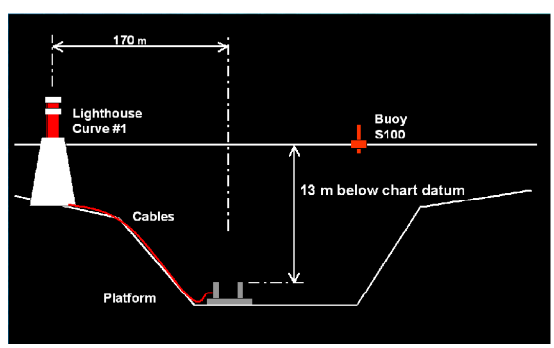

Fig. 5 Lake St. Pierre Installation

IV. REAL-TIME DATA SYSTEM

Fig. 6 shows the data path from the Courbe 1 station to the DFO intranet. The data files from Courbe 1, after being sent over the network to the CCG server in Quebec City, are processed by the IADDS (IPS and ADCP Data Display System) software, which then stores them in a database and creates graphical images for display on the SLIMS website.

In addition to the SLIMS website, ice managers may directly access the PC at Courbe 1 to view raw data acquired by the two instruments. The WinRiver window shows graphs of ice and water velocities, whereas the IpsRealTime window shows a graph of IPS range to the water surface or the underside of the ice (see Fig. 7).

As soon as they are received on the server, IPS, ADCP and atmospheric data are processed by the IADDS software. This software developed by ASL Environmental Sciences is designed to accommodate the following conditions:

- IPS, ADCP and atmospheric data may not come in at the same time.
- There may be delays in getting data for significant periods of time due to communications problems.
- Regeneration of the full database can be performed if there are changes made to some of the processing parameters or processing algorithms.
- As data are retrieved, the system produces web-compatible graphs that show specific data and computed values. These graphs are saved to files that are compatible for insertion into web pages.
- Three types of graphs for the different types of data are required for the web display. A daily graph for each day of data, an hourly graph showing the most recent data inserted into the database and a graph depicting data for the last 24 hours.

The IADDS software monitors the directories containing the ADCP, IPS and atmospheric files retrieved from Courbe 1. As new data files appear in the respective directories, the IADDS detects the new files by the archive flag status, retrieving specific data values from the new files and placing the data into the database. The files that have been read are marked by setting the file archive flag.

The database consists of a binary data file system with one file for each day of data. The structure of the files consists of 86400 records (number of seconds per day), which is the resolution of the IPS data. Each record has space for insertion of measured values from the IPS, ADCP and atmospheric data as well as computed values that require input from more than one source. The contents of each record are tracked with a flag to indicate the types of data available in that record. When any new data are received the full structure is recalculated to update computed values that were waiting on missing measurement values. The data processing includes range and quality indicator checks. IADDS provides the capability of exporting any portion of the data set for analysis on other systems.

As new data is retrieved and processed IADDS creates graphs showing full days of data and graphs showing the last hour of data. Table 1 shows a summary of the values that are retrieved and/or computed and then plotted on the graphs.

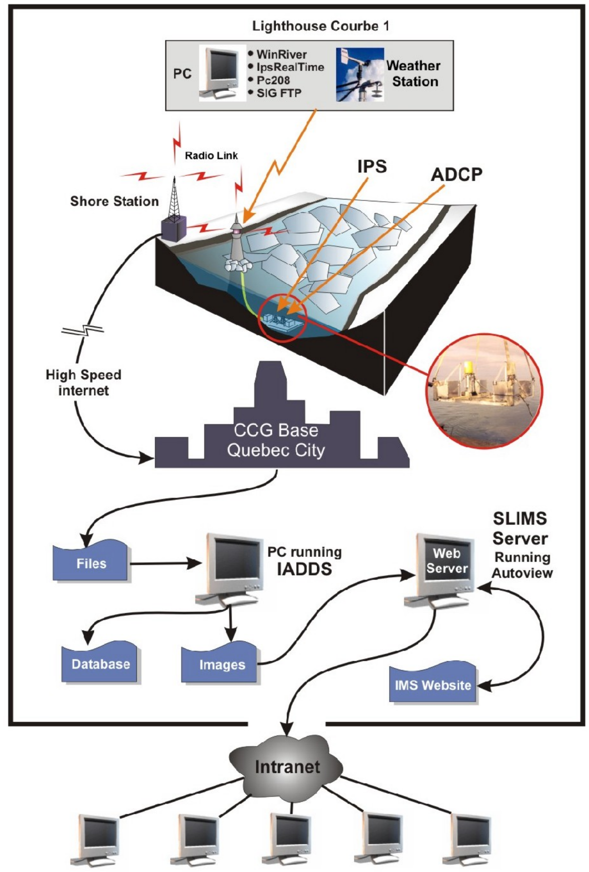

Fig. 6 Data Path

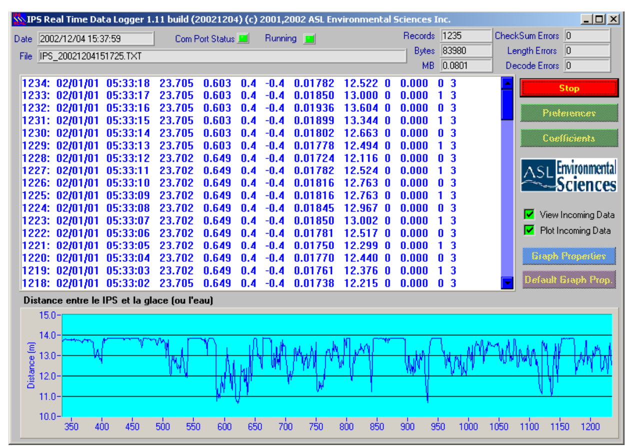

Fig. 7 IpsRealTime Display

TABLE 1 VALUES RETRIEVED OR COMPUTED

Quantity	Units	Source
Water Level	cm	IPS & Atmospheric
Ice Velocity	cm/sec	ADCP
Ice Direction	degrees	ADCP
Water Velocity	cm/sec	ADCP
Ice Draft	cm	IPS & Water Level
Ice Concentration	percent	Ice Draft
IPS Range	cm	IPS

Below are examples of the graphs produced by IADDS for inclusion into the SLIMS web site. Hourly graphs show instantaneous values (retrieved or computed). For example, Fig. 8 shows IPS range acquired every second, where one can easily distinguish between air/water and ice/water interfaces. Fig. 9 shows ice draft computed by IADDS every second. The daily graphs display mean values computed over a period specified by the user in the IADDS preferences (10 min in the figures below). Figs. 10 and 11 show clearly the increase in ice draft and concentration between the early and mid season. One must remember that ice concentration calculated from IPS data refers to the insonified width above the instrument, and not to the effective channel width. Figs. 12 and 13 show information crucial for ice managers in case of an ice jam: a decrease in ice and current velocities, combined with an increase in water level would indicate that an ice jam is developing.

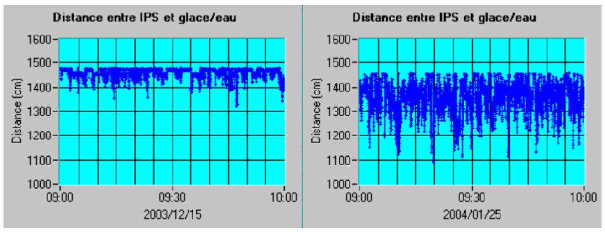

Fig. 8 IPS Range (early and mid season)

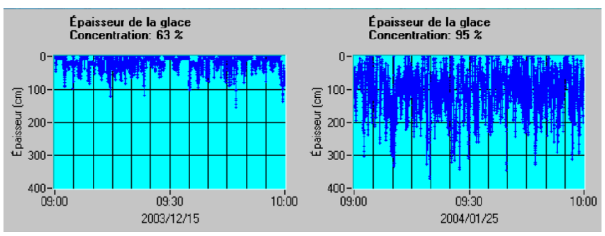

Fig. 9 Hourly Ice Draft (early and mid season)

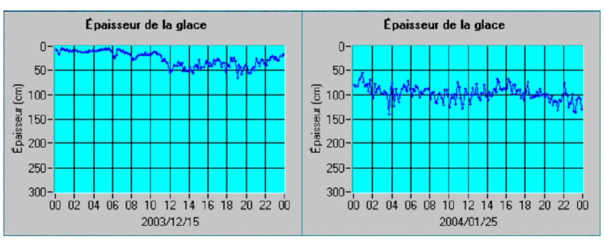

Fig. 10 Daily Ice Draft (early and mid season)

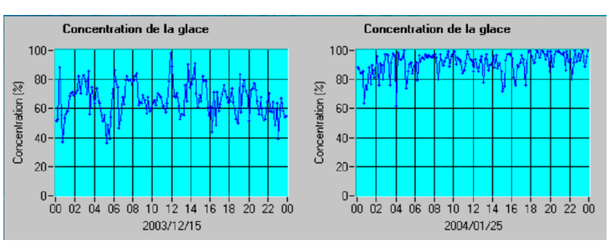

Fig.11 Daily Ice Concentration (early and mid season)

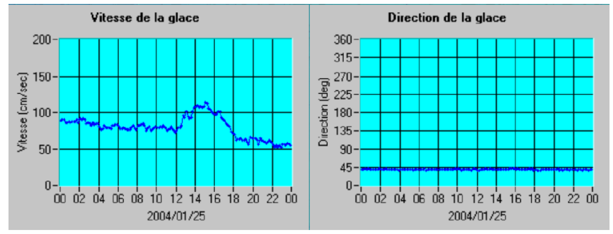

Fig. 12 Daily Ice Velocity and Direction

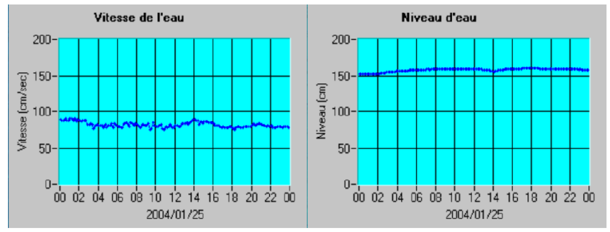

Fig. 13 Daily Current Velocity and Water Level

V. ON-SITE VALIDATION MEASUREMENTS

In January and February 2003, a field measurements campaign was conducted at Courbe 1 by the CCG to validate three ice parameters obtained by the IPS and ADCP instruments: thickness, velocity and concentration. Working from an icebreaker, floating ice keels and sails were measured with two cameras (one in the air, the other under the water) connected to a monitor. Ice floe velocity was evaluated from videos recorded with two cameras installed on the ice cover near the navigation channel, and ice concentration was estimated from aerial photographs.

Field data was analyzed by Professor Brian Morse of Laval University [1].Three series of ice thicknesses collected during three different days were analyzed; the mean values were 95, 109, and 72 cm. On average, it was found that the IPS underestimated the thickness by 13%, but the difference was not statistically significant. The manual measurements of ice velocity where within 2% of those estimated by the ADCP. The IPS concentration estimate was within 2% of the one estimated from photographs.

VI. CONCLUSIONS

The IPS and ADCP instruments form a reliable team to quantify ice and water flow characteristics. For the first time, the system implemented in the St. Lawrence River by the CCG provides *real-time*, *quantitative data* on ice conditions. Together with the other components of the SLIMS, it enables ice managers to rapidly take action in order to prevent and detect ice jams.

Future developments planned for the system include:

- Improvement of ADCP data processing in IADDS: the ADCP gives erroneous ice velocities when there is no ice to detect. Following the results of a study carried out by ASL and the CCG in 2004, the IADDS algorithm will be optimized to better distinguish between waves and ice.
- Automation of IPS deployment: except for the IPS, every component of Courbe 1 station can restart automatically following a power failure. This is not the case of the IPS instrument for two reasons: 1) a reset must be done manually to restart the IPS (at the present

time, this can be done with an APC switch remotely activated); 2) the deployment cannot be automatically started with IpsLink.

- Provide displays or computed values as outputs from IADDS for additional parameters, including horizontal ice floe scale sizes, water temperatures and perhaps others.
- Estimation of ice porosity with the IPS: return signal information from the IPS could be used to evaluate the capacity of the instrument to estimate the porosity of ice, which is an important characteristic of brash ice.

ACKNOWLEDGEMENTS

Brian Morse, professor at Laval University, who promoted and initiated the project in 1999.

Marc Choquette (CCG) and Marc Savard (CCG), who designed and deployed in a rather hostile environment the platform that cradles the IPS and ADCP instruments with success.

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