REALTIME MONITORING OF ICE THICKNESS AND GROWTH FROM SEAFLOOR-MOUNTED UPWARD-LOOKING SONAR INSTRUMENTATION

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Presented at POAC 2005

ABSTRACT

Realtime monitoring of ice thickness at fixed, relatively sheltered, polar and sub-polar locations has contributed important data relevant to both climate change (Brown and Cote, 1992; Flato and Brown, 1996) and in support of ice navigation guidance and assessment programs (Timco et al., 2003; Frederking, 2003). Unfortunately, the manual techniques historically used to acquire the great bulk of such data have in recent years led to the abandonment of many monitoring sites for economic reasons, depriving climatologists and the marine transportation industry of potentially useful information. ASL Environmental Sciences Inc, has addressed this situation through the development of inexpensive automated ice thickness monitoring instrumentation based upon an upward-looking sonar (ULS) ice draft measurement methodology (Melling et al., 1995) previously incorporated in an IPS4 Ice Profiler product widely used in a self-contained recording mode at offshore, deep ocean locations. The new instrument, the Shallow Water Ice Profiler Sonar (SWIPS), is designed to operate from seafloor locations adjacent to shoreline sites convenient for realtime data acquisition or on-shore data logging. Costs and instrument loss risks are minimized by limiting seafloor components to an acoustic transducer, and hydrostatic pressure-, temperature- and (optional) tilt-sensors. The seafloor portion of the instrument is linked by cable to a shore-based electronics package which carries out all control, acoustics generation and signal detection- and data logging- and data storage-functions. This instrument is now capable of unattended collection and recording of draft time series data at shallow water monitoring sites of interest. Near-realtime data relay through a satellite link is a likely future addition to its capabilities. Results will be presented and discussed from a recent SWIP deployment in application to freshwater river ice monitoring.

INTRODUCTION AND AN OUTLINE OF THE PROBLEM

The development, in the 1990's, of capabilities for obtaining accurate time series measures of the draft of a moving ice cover from moored or sea-floor based upward-looking sonar instrumentation has contributed greatly to our quantitative understandings of ice cover composition and character (Melling et al., 1995; Fissel et al., 2004). The resulting knowledge has been widely applied to numerous offshore hydrocarbon production design and operation programs in the Arctic Basin and the northern Pacific Ocean. Similar data, gathered over more than a decade in the Beaufort Sea, the Antarctic and other Arctic and sub-Arctic regions, have also provided a database of growing importance to ongoing efforts to monitor and characterize climate change. In both instances, movement or drift in the studied ice cover have been essential requirements since ice velocity data extracted with the bottom-tracking feature of adjacently-deployed acoustic Doppler current profilers (ADCP) (Figure 1) are essential to conversion of ULS range time series into pseudo-profiles along linear tracks across ice cover undersurfaces (Figure 2).

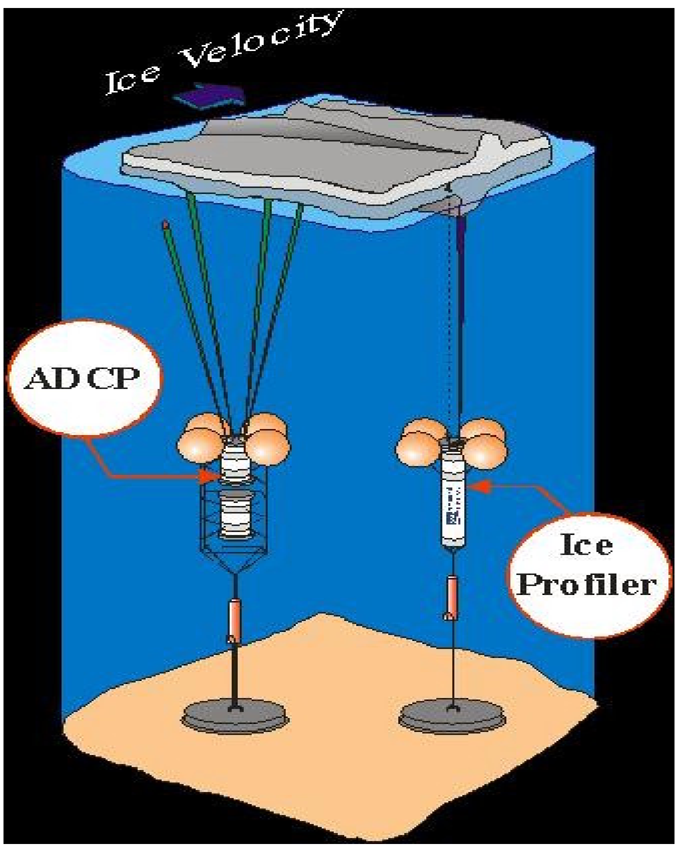


Figure 1. A typical deep-water ice profiling site with Ice Profiler and ADCP instruments deployed on adjacent, independent, moorings. The instruments are typically deployed at depths of 30 to 100 m in total water depths of 30 to 200m.

Additional applications of this self-recording ice profiling technology have been directed at investigations of potential port sites based upon analyses of accumulated information on ice thickness and scales of horizontal variability. Over-winter measurement programs of this type have been carried out near Sakhalin Island, in eastern Canada and along the Arctic coastline of Russia.

In recent years, needs have become apparent for extensions of this technology to realtime draft monitoring and to stationary ice covers. In the first instance, rapid access to profile and thickness data has been required for ship and ice management programs such as those maintained by the Canadian Coast Guard in the St. Lawrence River (Dumont et al., 2001). A recent evaluation (Morse et al., 2003) of several years of data collected in the latter effort confirmed the accuracy of ice draft data received at a central command centre, via a VHF link, after acquisition by an ASL Environmental Sciences' IPS4 Ice Profiler. A realtime Ice Profiler Sonar (IPS) and ADCP Data Display System (IADDS) has been recently developed and implemented at the St. Lawrence site to facilitate rapid exploitation of data acquired from IPS4 and RDI ADCP units (Chave et al., 2004).

The second type of application, to stationary-, or to, at least, frequently stationary-, ice covers, has been motivated by an evident need to facilitate continuance of ice thickness data collection at sheltered and remote marine locations in the Canadian Arctic and elsewhere where ice grows in place and without sustained movement. The Canadian Arctic data sets in question extend back into the 1940's, although the most useful measurements, taken at weekly time intervals, were initiated in 1952 (Brown and Cote, 1992). Given the known presence of prominent climate cycles with periodicities as large as and much larger than several decades (Stanley, 1999), the temporal lengths of these records and the locations of their associated data-taking make them one of the crown jewels of the world database for detecting and understanding high latitude aspects of climate change (Brown and Flato, 1996). As well, the locations of many of the Canadian monitoring sites in the Canadian Arctic Archipelago make the data immediately relevant for assessing the reality and/or the pace of an anticipated (Falkingham et al., 2001) clearing in the channels of the Northwest Passage, the long-heralded potential route for marine traffic between the North Atlantic and Pacific Oceans. Continued thickness monitoring at such sites would appear to be a sensible component of initial planning efforts for development of all High Arctic marine transport routes.

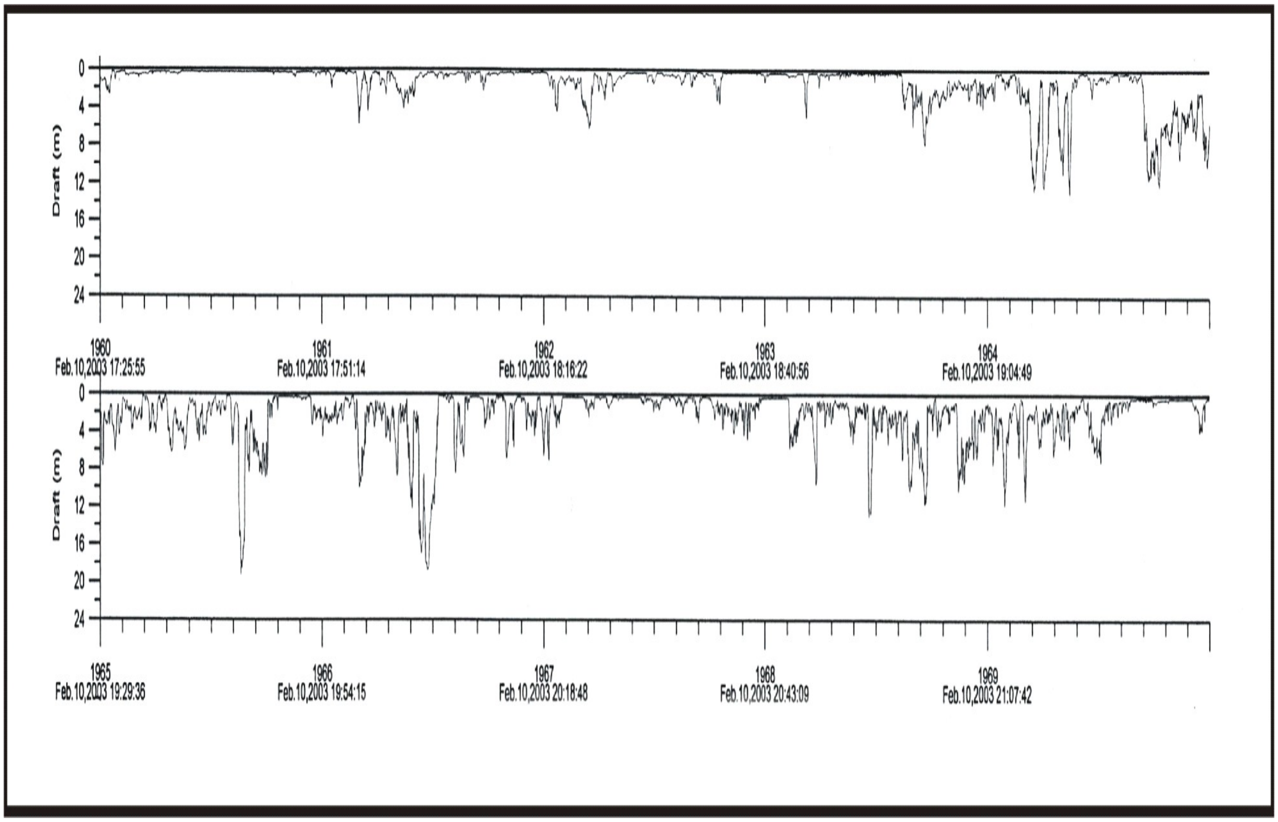


Figure 2. A plot of ice draft along a linear ice cover track in the Sea of Okhotsk.

Unfortunately, the manual methods historically used to gather such data (i.e. drilling holes in the ice covers of interest) have been and continue to be costly in terms of manpower, logistics and support facilities. Consequent economic constrictions have already necessitated one cessation (2000-2002) in the Canadian measurement program. The subsequent restarting and continuance of this effort have been provisional and subject to possible termination in the near future. The availability of an option for inexpensive remote thickness/draft monitoring in such locations could minimize chances of further interruptions in the Canadian data-taking and, possibly, could encourage acquisition of equivalent data at more widely spread seasonally- and perennially-ice-covered regions.

The development of a prototype instrument suitable for such measurements is described below. Its underlying operational concepts and advantages over other options for equivalent data-taking are summarized prior to description of a prototype instrument and the results from its initial testing at an ice-covered river site.

FEASIBILITY OF ECONOMICAL SHALLOW WATER ICE PROFILING

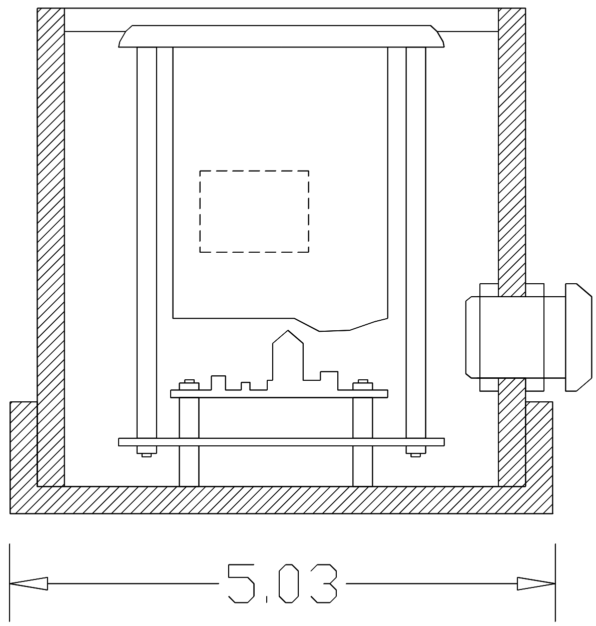
Marine ice draft measurements are typically made from moored offshore instrument arrays such as the one pictured in Figure 1 based upon an ASL Environmental Sciences' IPS4 Ice Profiler. The latter instrument is designed to operate unattended for as long as two years, recording range and auxiliary data at frequencies as high as once per second for use in conjunction with ice velocity data to accurately produce profiles such as those reproduced in Figure 2. Although economical compared to alternative methods, the extent of usage of this technique for deep-water marine ice profiling tends to be limited by the considerable costs involved in deployment and recovery and, as well, by the delays and uncertainties intrinsic to achieving recovery and access to the collected data. Equivalent difficulties can usually be avoided in shallow water ice thickness/draft measurements if measurements are made, as in the past, adjacent to existing meteorological data gathering stations which are either permanently-manned or periodically visited for maintenance or data-downloading purposes. If the underwater components are limited to the transmitting/receiving transducer, ancillary sensors and their common mounting, the instrument can be put in place and serviced in the usually available open water season, with such efforts, in most cases, limited to removal of biofouling material. Confinement of all instrument control, signal generation and data storage electronics to a shoreline module would eliminate and the costs and risks posed by pressure case packaging of deep-water instrument electronics and greatly simplifies access for trouble-shooting, data-downloading and changing measurement parameters. Such stations also, typically, already acquire the water level data required for converting range into draft data from pressure gauges placed on the sea floor. This circumstance eliminates requirements for the inclusion of the high accuracy, deep-water pressure gauges which make significant (20%) contributions to the costs of offshore profilers. As well, the usually greater stability of the water column in sheltered monitoring areas greatly simplifies data processing by reducing levels of effort involved in following and quantifying sound speed changes

Underwater cables can provide both power and access for instrument control and facilitate direct readout and downloading of data. Removal of pulse generation-, electronic control- and data storage-functionalities from the underwater components of such instruments allows considerable cost savings and, as well, enables routine acquisition of additional data directly relevant to the accuracy and content of the information gathered on the ice cover of interest. In practice, this change allows users to optimize key acoustic parameters such as receiver gains and pulse-amplitudes, -widths and –repetition frequencies in the presence of possible changes in environmental conditions.

A prototype of a new Shallow Water Ice Profiling Sonar (SWIPS) instrument was designed and built to take advantage of these benefits. Its features and results from initial tests will be described below.

THE SWIPS PROTOTYPE: DESIGN AND TESTING

The SWIPS prototype was constructed, locally tested and is now being operated at a river-bottom site on the Peace River in Alberta, Canada as a source of data for early detection of ice jams (Jasek et al., 2005). The underwater portion of the instrument was mounted on a waterproofed concrete block affixed to the river bottom and linked to an adjacent instrument shack about 100 m away by a 6-conductor cable (Figure 3). The minimal components of the underwater package (Figure 4) included a commercial grade



235 kHz ceramic transducer, a thermometer and a two axis tilt sensor which were mounted in a potting compound inside a 4" piece of PVC pipe. The pipe was attached to four pieces of protective rebar set into the concrete block. The transducer incorporated a transformer to insure adequate analog signal levels at the landward cable terminus. The transducer's 11º beamwidth (relative to the -3 dB levels) exceeded the beamwidths normally associated with conventional deepwater profilers by more than a factor of 5 but, still, for water depths of 10 m or less, allowed sampling footprints no larger than 1.5 m in diameter.

The shoreline electronics (Figure 5) acquired analog acoustic signal return-, water temperature- and concrete block tilt-data which enabled acoustic range measurements to made at selectable time intervals from the returns of individual 68 microsecond pulsed signal transmissions. In initial tests, data on ranges to the ice undersurface were collected at 1 Hz while complete pulse profiles were recorded every 12 s. Signal returns were digitized at 35 kHz and the associated single point ranges and profiles stored together with temperature and tilt data in the SWIPS 64 Mb flash memory. Hydrostatic pressure information was not incorporated into the data stream as such data were being acquired at a separate self-recording gauge mounted on the concrete block next to the SWIPS.

Figure 3. Sketch of transducer, tilt gauge and thermometer in casing. A measure of scale is given by the container width indicator expressed in inches.

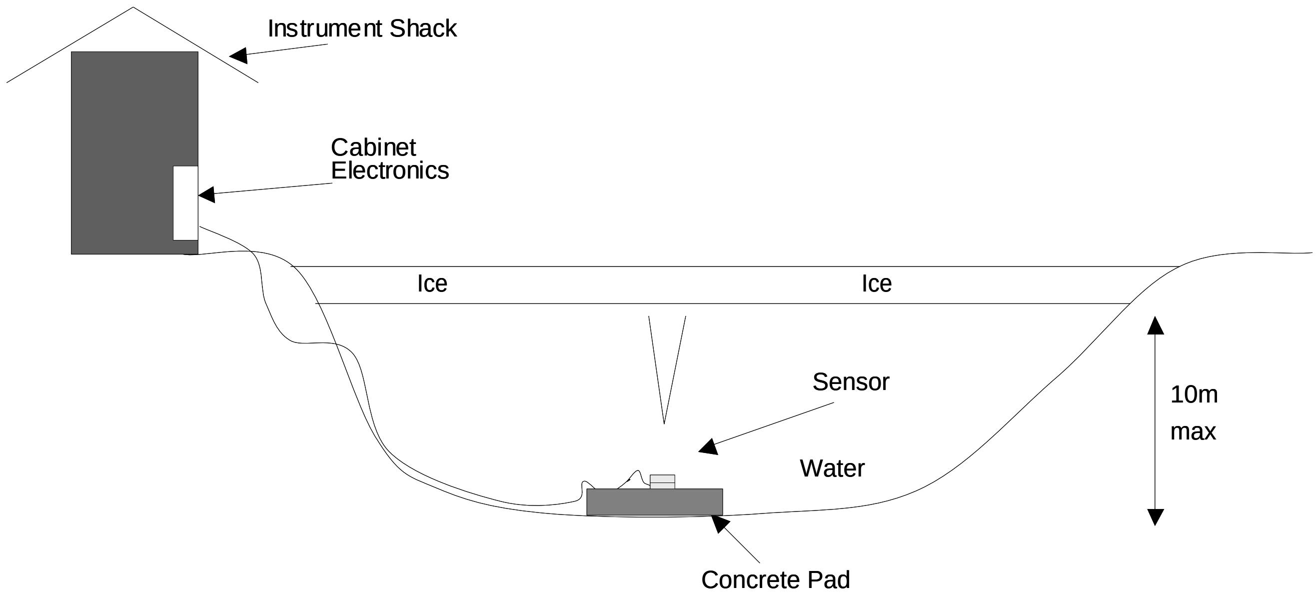


Figure 4. Sketch of Peace River test deployment configuration.

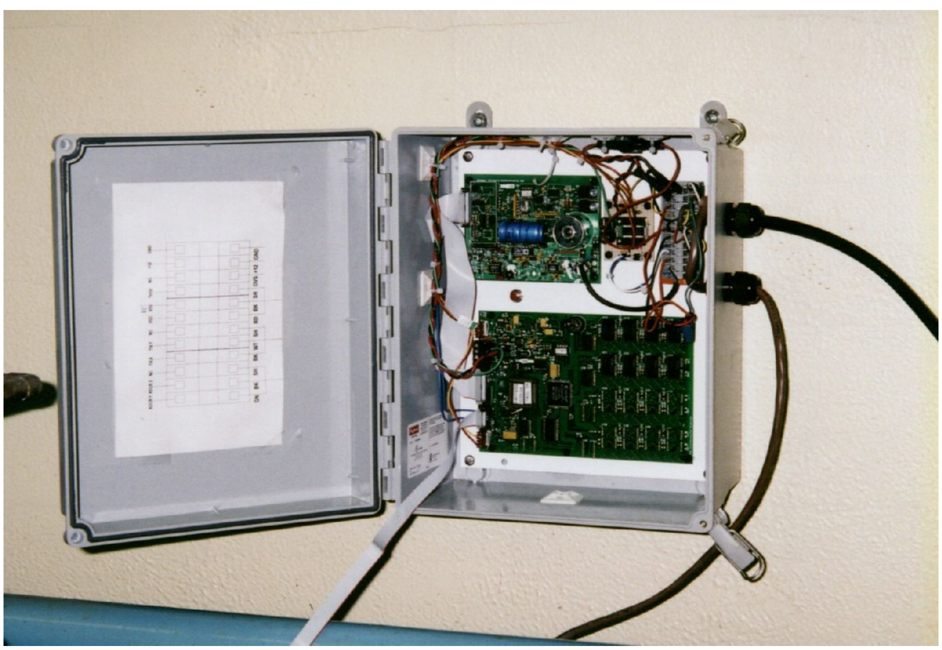


Figure 5. Photograph of the SWIPS shore-based electronics and control unit.

The prototype SWIPS has operated continuously and successfully from December, 2004 into spring 2005. Data were periodically downloaded with a laptop computer to provide measures of instrument performance and ice conditions. Fully detailed analyses await final recovery of the instrument and consequent access to the hydrostatic pressure database. Detailed results from such analyses will be presented elsewhere (Jasek et al., 2005). Data processed to date with SWIPSLINK software have documented the appearance, growth and deterioration of the seasonal, mostly landfast, ice cover. A single break in coverage was experienced during a, roughly, week-long period in early January when the accumulation of anchor ice on the SWIPS transducer face interrupted reception of return signals from the river ice cover. Preliminary analyses have indicated that the detected sharp increases in signal returns normally associated with the undersurface of the ice cover correspond to the bottom portion of the "slush " ice which characteristically collects under the "hard" landfast ice visible on the river surface. This sensitivity of ice profiling to the lowest recognizable ice surface has been noted previously in conventional marine applications by Belliveau et al. (2001). In the present case, however, the shore station's capability for acquiring and storing data on the complete SWIPS return pulse signal allowed additional extraction of quantitative data on both the slush ice and the overlying hard ice cover. Such a capability has not, to date, been available in conventional marine ice profilers which, because of their limited capacities for data storage, have focused attention on collecting data from the leading edges of the observed pulsed signal returns.

CONCLUSIONS

Bottom-mounted, upward-looking sonars are a proven technology for both scientific studies of climate change and for pre-construction data-gathering related to developing and operating new port and offshore structure facilities in ice-infested regions. Inexpensive, realtime implementations of this technology have now been developed and demonstrated. This advance now allows addressing an important existing need for continuation of climate-change- and navigation-related ice thickness monitoring in shallow water marine locations at very modest financial, logistical and manpower costs using shoreline stations, many of which are presently operated as parts of national/international meteorological and navigation assistance networks. The obtained data can enhance the value of existing ice thickness archives and, utilizing existing reporting mechanisms, can make information on potentially important environmental factors available to forecasters and route planners. In particular, the SWIPS instrument offers an economical new realtime input to guide both coastal climate forecasters and marine route managers charged with controlling access on the basis of en route and local ice conditions. The new generation of instrument also has direct application to operations of ports in ice-infested waters.

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