Real-Time Measurement of Sea Ice Thickness, Keel Sizes and Distributions and Ice Velocities Using Upward Looking Sonar Instruments

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***Abstract*- There is an increasing requirement for real-time underwater measurements of sea ice keel properties, including thickness and sizes of individual keels and of ice velocities. Such information is needed in real-time to support tactical applications for safe routing of ships in heavy sea ice concentrations and, more recently, a need for tactical support of offshore oil and gas activities in ice infested waters of the Arctic Ocean and in marginal ice areas such as the Sea of Okhotsk, the Caspian Sea, Baffin Bay, the Labrador Sea and East Greenland waters. Reliable upward looking sonar (ULS) instruments, including the ASL Ice Profiler for ice keel measurements and the Acoustic Doppler Current Profiler for Ice Velocity measurements have been widely used in these areas for many years. These instruments, which record data internally, are operated from subsurface moorings that are deployed and recovered by ship during times of minimal sea ice coverage.**

Providing real-time measurements from the upward looking sonar measurements operating under heavy ice cover pose new technological challenges. The use of surface buoys to relay data from subsurface instruments to shore facilities or satellites is not possible due to the ice cover itself. A more feasible approach is to transmit the data from each instrument using underwater cables on the sea floor and which link the instruments on the subsurface moorings to a bottom mounted or floating structure. For a floating structure, the use of high performance acoustic modems may be required.

Previous experience with real-time ULS ice measurement systems is presented based on operational projects undertaken from 2002 to the present. The projects are based on experience in the St. Lawrence Seaway (since 2002), and more recent work at the Confederation Bridge in Canada (2005-2008), and the Caspian Sea (2008). The approaches taken to addressing the real-time measurement of the subsea ice keels are summarized for each application.

More challenging requirements for real-time ULS ice measurement systems are being addressed in much deeper and more remote areas of the Arctic Ocean. In these areas of more prolonged and severe ice conditions, the deployment of the system is limited to late summer periods when ice coverage is reduced. The requirements for timely and accurate ice information demand high reliability in support of ship navigation and offshore oil and gas drilling applications. The real-time ULS ice measurement system must be capable of operating for two to three years without servicing. Multiple ULS measurement arrays will be needed over operational areas spanning distances of many kilometers. For these Arctic Ocean applications, cabled ocean observatory technology and advanced underwater acoustic modems become key enabling technologies.

I. INTRODUCTION

The need for real-time underwater measurements of sea ice keel properties, including thickness and sizes of individual keels and of ice velocities is increasing as marine activities expand within marginal ice zones and polar regions. The marine applications for real-time sea ice data is twofold: for support tactical applications for safe routing of ships in heavy sea ice concentrations; and, more recently, a need for tactical support of offshore oil and gas activities. Driven by the impetus of increasingly scarce oil and gas reserves, offshore petroleum production has begun in ice infested areas including the marginal ice zones of the Northern Hemisphere including the Canadian East Coast, the Sea of Okhotsk (Russia), the Caspian Sea (Kazakhstan), the Bohai Sea (China) and even within the near shore areas of the Arctic Ocean in Alaska. Recent studies [1] indicate great potential for very large oil and gas as well as mineral reserves in the Arctic Ocean, which combined with increased shipping access, may lead to much greater human activities and the need for real-time tactical data for sea ice in support of these activities.

Providing real-time measurements from the upward looking sonar measurements operating under heavy ice cover pose new technological challenges. The use of surface buoys to relay data from subsurface instruments to shore facilities or satellites is not possible due to the ice cover itself. A more feasible approach is to transmit the data from each instrument using underwater cables on the sea floor and which link the instruments on the subsurface moorings to a bottom mounted or floating structure such as a drillship or production platform. For a floating structure, the use of high performance acoustic modems may be required. In areas closer to land, the underwater cables can be installed across shorelines, with suitable protection from ice scouring, to allow the data to be transmitted via satellite to operations centers and vessels.

II. MEASUREMENT PRINCIPLES AND INSTRUMENTATION

Reliable upward looking sonar (ULS) instruments, including the ASL Ice Profiler Sonar (IPS) for ice keel measurements and the Acoustic Doppler Current Profiler for ice velocity measurements have been widely used in ice infested ocean regions for many years (Fig. 1). These instruments, which record data internally, are operated from subsurface moorings that are deployed and recovered by ship during times of minimal sea ice coverage.

The IPS is an existing and proven instrument manufactured by ASL Environmental Sciences Inc., of Victoria BC Canada, which is capable of providing real-time output via a RS-232/422 serial data protocol through a bulk-head underwater connector. The IPS has become the industry standard for upward looking sonar measurements of sea ice keels, and it is has been widely used for one year or longer deployments in the Arctic Ocean and marginal ice zones. Because of the extended deployment periods, the instrument features very low power consumption and operates over one year periods or longer using an internal 8 layer alkaline battery pack.

The IPS operates by emitting and detecting surface returns from frequent short pulses (pings) of acoustic energy concentrated in narrow beams (less than 2° at half power). Precise measurements of the delay times between ping emission and reception are converted into ranges separating the instrument's transducer and the ice under surface.

Contemporary data from the instrument's on-board pressure sensor are combined with atmospheric surface pressure data and estimates of the mean sound speed in the upper water column (obtained from data collected during absences of ice above the instrument) to derive estimates of ice draft from each emitted ping. The instrument also measures water temperature and x- and y-tilt values. Typically the IPS is operated at water depths of 40 to 60 m with a horizontal resolution at the surface of 1.3 to 2 m.

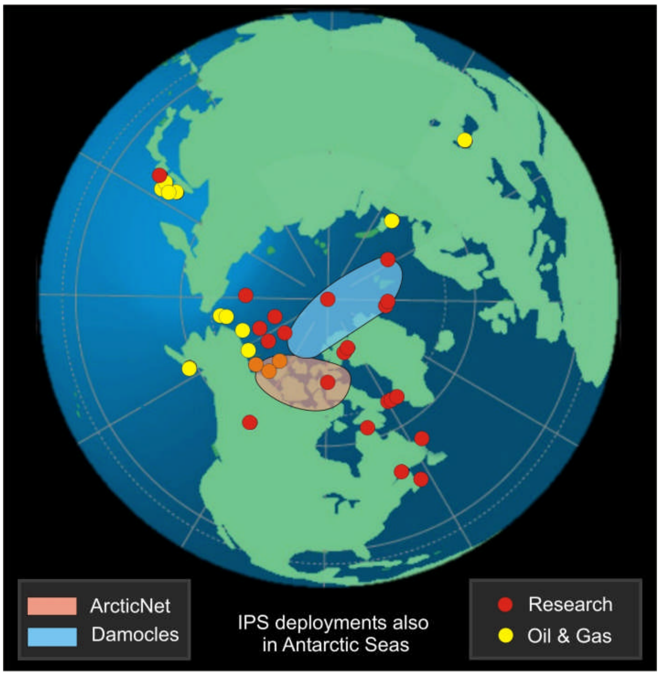

Figure 1: A map showing the locations of Ice Profiler Sonar deployments in the 1990's and 2000's in the Northern Hemisphere.

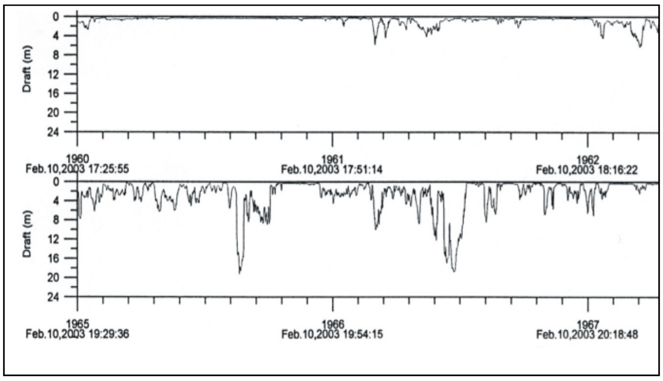

Figure 2: A very short segment of less than 3 hours duration from the Sakhalin Shelf in the Sea of Okhotsk (taken from an eight month data record).

At the usual ping rate of 1 Hz, and with typical ice velocities of < 0.1 to 0.8 m/s, the instrument can fully resolve ice keel features at a resolution of 2 m or better. With suitable data processing, the accuracy of the 1 Hz ice draft values is 0.1 m. A sample segment of IPS derived ice drafts, spanning less than 3 hours, is shown below in Fig. 2.

III. SUBSEA ICE MEASUREMENT SYSTEMS

Previous experience with real-time ULS ice measurement systems is presented based on operational projects undertaken from 2002 to the present. The projects are based on experience in the St. Lawrence Seaway (since 2002), and more recent work at the Confederation Bridge in Canada (2005-2008), and the Caspian Sea (2008).

A. St. Lawrence Seaway

In the St. Lawrence Seaway system, 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. Aerial and satellite surveillance provides ice coverage data, but not thickness. A real-time system for measuring the underside properties of the sea ice was first installed in the St. Lawrence Seaway in 2002 and was operated until 2007 [2].

The IPS (Ice Profiling Sonar) and ADCP Data Display System (IADDS) consists of the two submerged ULS instruments (IPS and ADCP), connected by cable to a nearby lighthouse that is equipped with a computer, and weather station. 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. Fig. 3 provides an overview of the major modules and data flow of the St. Lawrence River ice monitoring system.

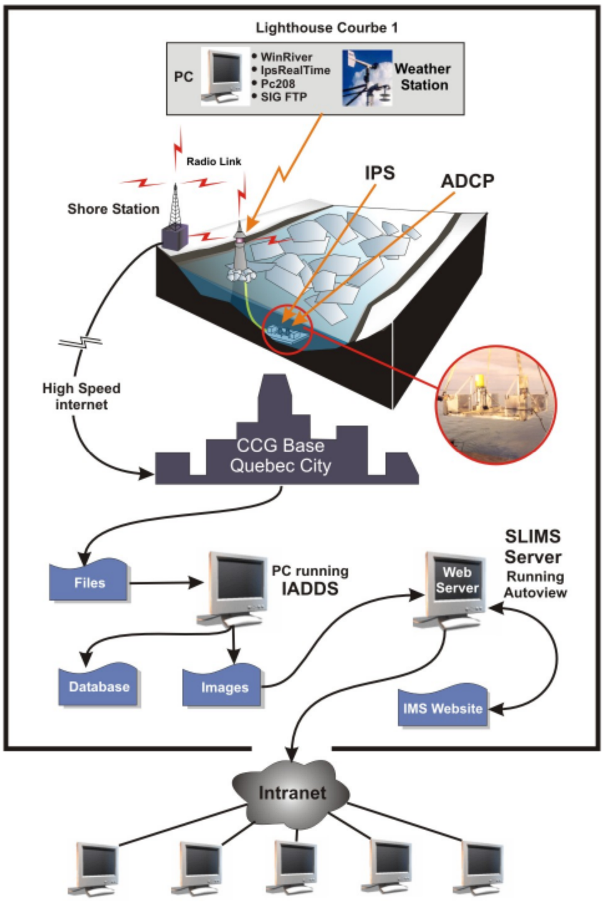

Figure 3: an overview of the components and data flow of the St. Lawrence River ice monitoring system.

Once the data is received at the headquarters, the IADDS system running on a PC computer at headquarters automatically generates a sequence of standard data products which are inserted in a database. The standard data products include ice drafts, ice concentration, water level, ice velocity, ice direction and IPS ranges. The data is plotted and images compatible for inclusion into WEB pages are created.

Examples of the data displays (Fig. 4) show data collected during the winter season from about December to March. The example graphs below generated by the IADDS show early and mid season data. The hourly graphs show instantaneous values. The daily graphs display mean values computed over a period specified by the user in the IADDS preferences.

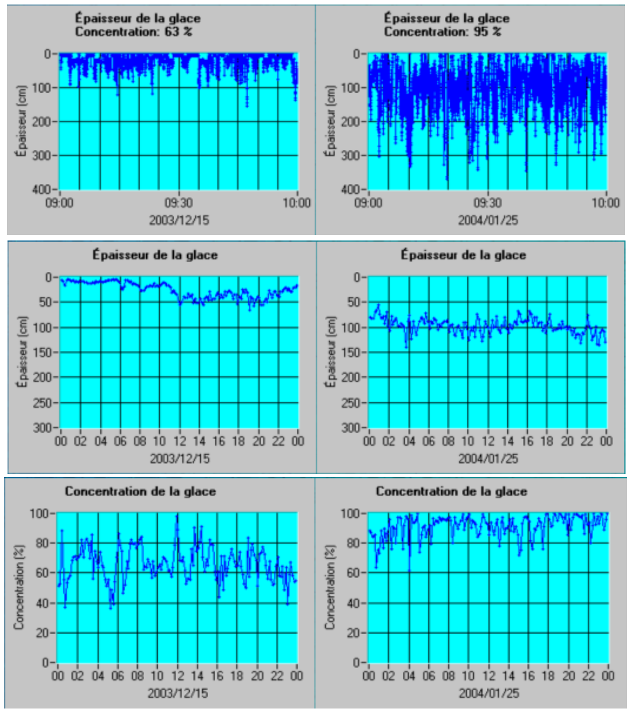

Figure 4: Examples of data displays from the St. Lawrence ice monitoring system for the early and mid season: (upper) hourly ice draft; (middle) daily ice draft; (lower) daily ice concentration.

B. Confederation Bridge, Northumberland Strait, Canada

A similar system involving an IPS instrument was operated from the Confederation Bridge in Northumberland Strait (see Fig. 5 and Fig. 6) starting in 2005 with continuing operations each ice season through to the present. In this system, the IPS instrument was deployed in the fall (Fig. 7) prior to the development of sea ice cover with an underwater multi-conductor cable attached that was laid out on the seafloor and onward to one of the bridge piers where the cable was fed into an online computer in an interior lab within the bridge.

Figure 5: Confederation Bridge with sea ice cover in Northumberland Strait, Eastern Canada.

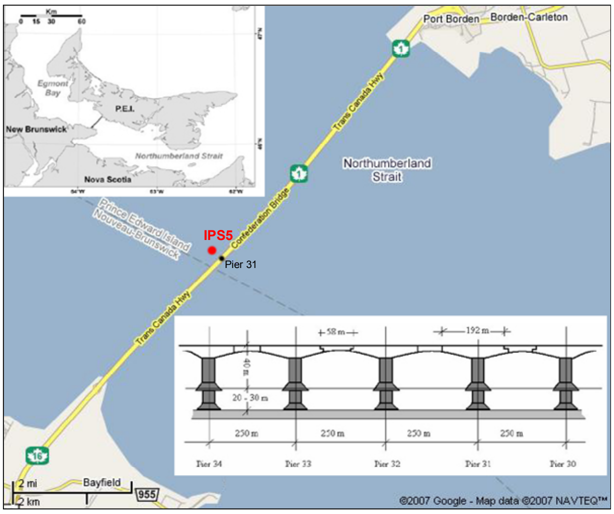

Figure 6: The location of the Ice Profiler (IPS5) near Pier 31 of the Confederation Bridge. Also shown are the location of Northumberland Strait in Eastern Canada and a diagram of the instrumented bridge piers [8] near the IPS5 instrument.

The Ice Profiler model IPS5 instrument communicated with the bridge computer using the RS-422 serial data protocol. Data could be accessed and downloaded remotely through and internet connection from the bridge computer and the instrument sampling parameters can be modified remotely via this communication system. Further information on the overall program and final processed results are presented in [3] and [4]. The use of the Ice Profiler model IPS5 provided the capability to measure ocean waves over user-set burst durations (in this case 17 minute wave bursts each hour using 2 Hz wave sampling).

Figure 7: Ice Profiler Sonar model IPS5 mounted on a bottom mooring.

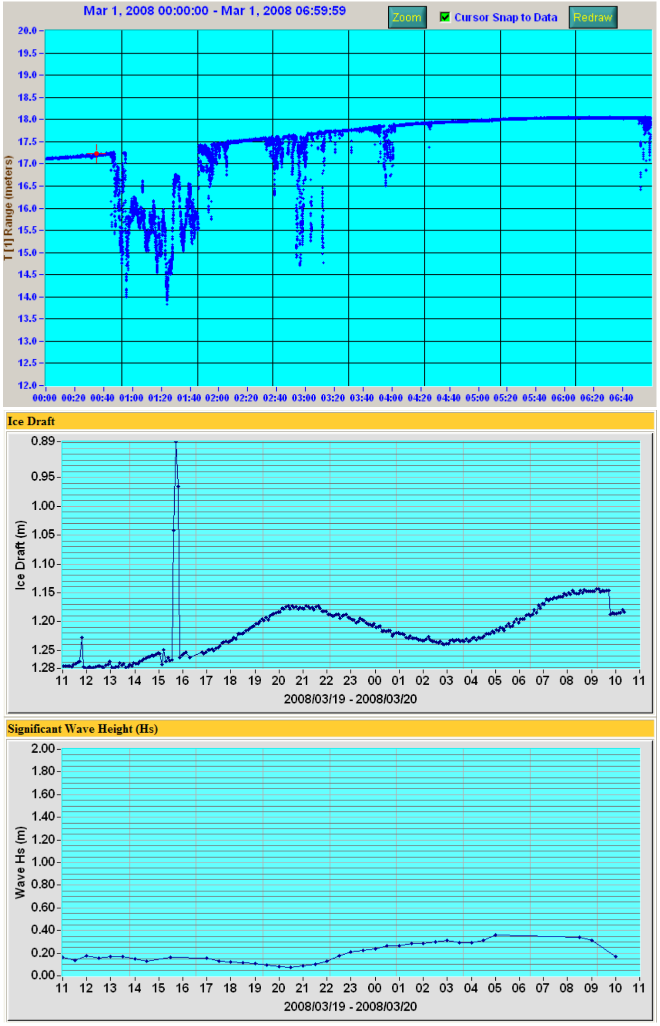

Figure 8: Sample of near real-time data displays from the Confederation Bridge showing: ranges to ice targets (upper panel); ice drafts (middle panel) and significant wave heights (lower panel).

Examples of the real-time data results obtained from the IADDS modified software operated at ASL Environmental Sciences Inc. in British Columbia, Canada located some 6,000 kilometers away from the Confederation Bridge are presented in Fig. 8. The use of a high speed internet access on the Confederation Bridge allowed reliable and readily accessible data products to be generated with the ASL computer in near real-time.

C. North East Caspian Sea

More recently, a real-time Ice Wave Measurement System (IWMS) was developed for an oil and gas application in the shallow waters of approximately 30 m water depth in the NE Caspian Sea. The Ice Profiler model IPS5 instrument was mounted on a low profile bottom frame (Fig. 9) with real-time serial output transferred through an underwater cable to a fixed structure within a few hundred meters of the measurement location (Fig. 10).

Figure 9: The low profile aluminum bottom frame for Ice Profiler Sonars as used in the NE Caspian Sea.

Special software and firmware was developed to provide real-time ice draft and/or wave information on a PC Windows computer located on the nearby drilling platform.

This IWMS system operates much the same way as the IADDS system producing ice information such as Ice Drafts and producing output compatible for viewing with a web browser. The IWMS has the added capability of monitoring waves if no ice is present. An example of the range to surface targets obtained by the IPS5 along with the computed wave spectra is shown in Fig. 11.

Like the IADDS system discussed above, the IWMS system produces images and text output that can be viewed using a standard WEB browser. Since the data acquisition system is networked, ice draft and ice velocity can frame.

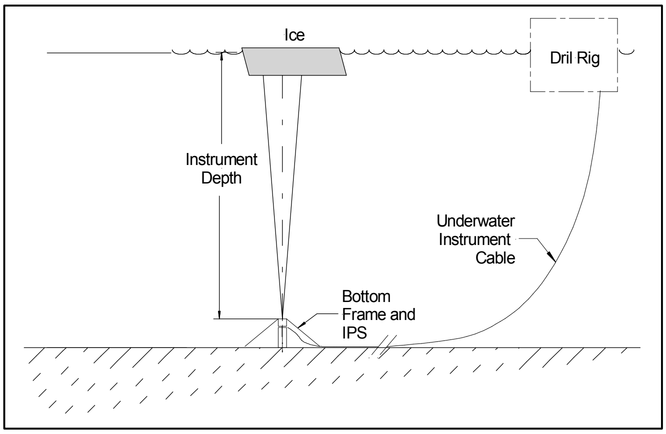

Figure 10: A diagram of the real-time Ice Profiler with data cable connection to a drilling rig in the NE Caspian Sea.

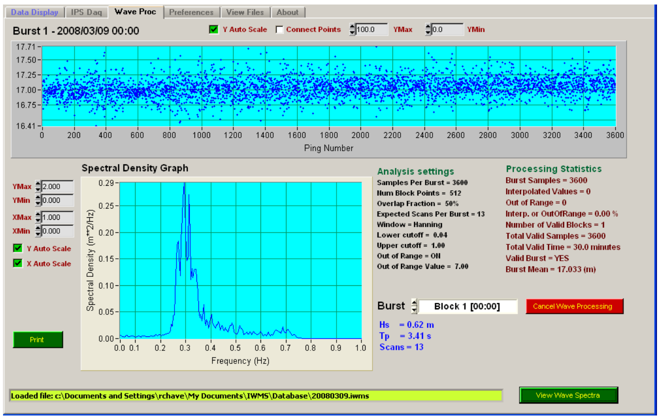

Figure 11: A web display output from IWMS showing the range to surface targets obtained by the IPS5 along with the computed wave spectra.

IV. Emerging Applications

More challenging requirements for real-time ULS ice measurement systems are being addressed in much deeper and more remote areas of the Arctic Ocean. In these areas of more prolonged and severe ice conditions, the deployment of the system is limited to early summer to late autumn periods when ice coverage is generally reduced with episodes of threatening ice conditions. The requirements for timely and accurate ice information demand high reliability in support of ship navigation and offshore oil and gas drilling applications. The real-time ULS ice measurement system must be capable of operating for two to three years without servicing. Multiple ULS measurement arrays will be needed over operational areas spanning distances of many kilometers. For these Arctic Ocean applications, cabled ocean observatory technology and advanced underwater acoustic modems become key enabling technologies.

Early conceptual design studies are now underway to deal with these demanding requirements. Given the large separation between the instrument clusters within the full measurement array system, the use of underwater fiber optics cables is being considered for these applications. In recent years many advances in these technologies have been achieved through the underwater cabled observatory programs funded for real-time ocean observations systems in temperature waters such as the Ocean Network Canada's VENUS and Neptune Canada observatories [5]. In addition to underwater fiber optic cables on the sea-bed, acoustic modems may be used as a data link to the instrument clusters which could be several hundred meters above the sea-bed. Acoustic modems may also represent a suitable approach for sending data between the central node of the underwater cabled network and floating units such as a drillship or a production platform. A schematic diagram showing some of the key elements of a deepwater Arctic real-time ULS measurement system for sea ice is shown in Fig. 12.

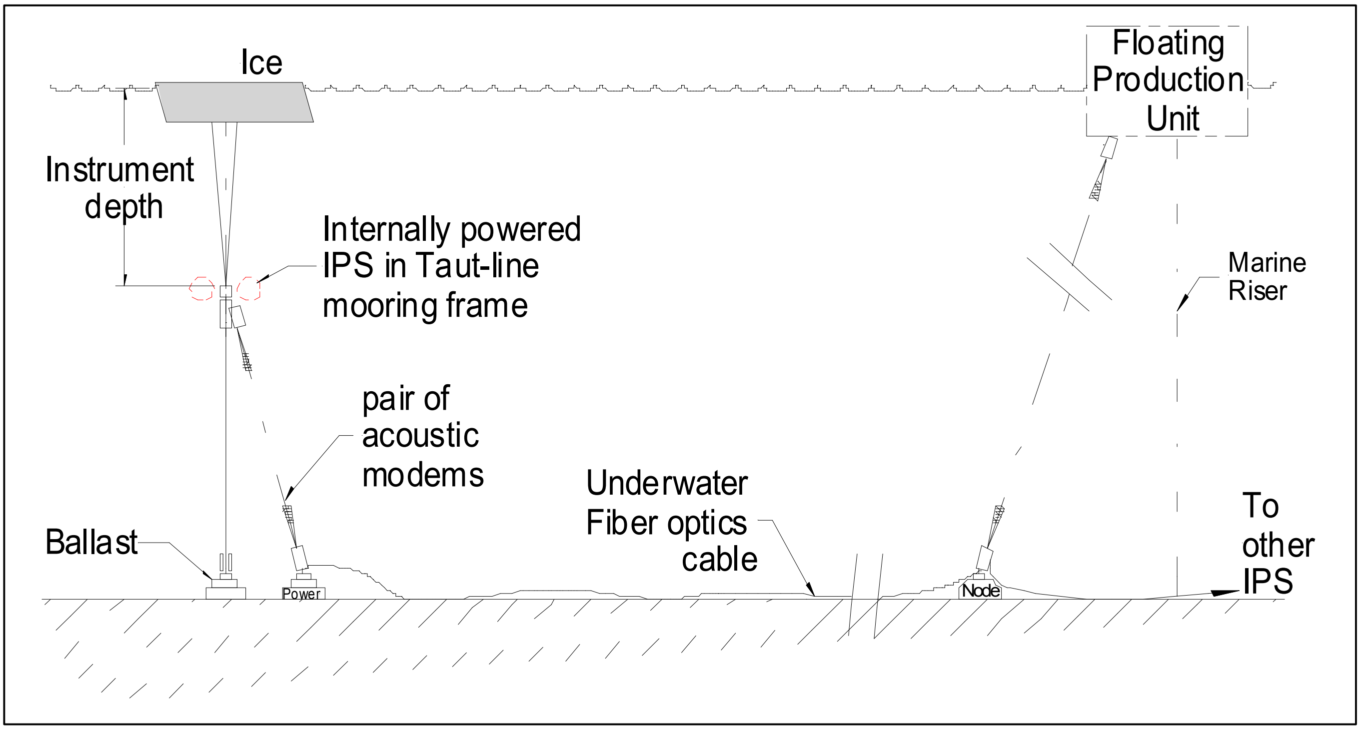

Figure 12: A high level schematic diagram of a deepwater Arctic Ocean real-time measurement system using Upward Looking Sonar instruments for measurement of sea ice keels and ice velocities in support of offshore resource extraction activities.

In the early conceptual design work, key system design issues that must be addressed include: power sources for self-powered systems (distributed long-life battery systems vs. a much larger central power source); the optimal location of the instrument arrays to provide adequate coverage of the area of operations; installation and maintenance requirements; and the real-time data processing and display methods to effectively present information that can be used for tactical ice management purposes that complements other sources of information from above the floating ice cover such as ship-based radar and visual observations and satellite derived information on sea ice cover.

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