Applications of ice profiling sonar technology to scientific, engineering and operational issues in Polar and sub-Polar waters

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Motivation

Accurate data on ice draft and its variations are relevant to:

1. quantifying and understanding **natural/anthropogenic climate change**;
2. facilitating human activities (i.e. marine navigation) in ice-infested waters;
3. structural design of transport and resource extraction structures in cold marine climates.

The Ice Profiling Tool

ASL Environmental Sciences' **Ice Profiler** (originally developed at the Institute of Ocean Sciences, Patricia Bay) is a state of the art upward-looking sonar specifically designed to acquire range, direction and instrument attitude data with **detail and accuracy** sufficient to measure ice draft values to **accuracies of, in most cases, +/- 5 cm**. Key system parameters, listed in **Table 1,** are a **narrow conical beam** and a **high, ≤ 2 Hz, sampling rate** which allow detailed, high spatial resolution, ice cover sampling and, enhanced capabilities for accurate ranging to (often) rare stretches of open water or very thin ice. The latter capabilities are essential for accurately following changes in sound speed which are the principal limitation to accurate draft measurements.

Table 1. IPS-4 Ice Profiler System Parameters

Operating Frequency	420 kHz
Beam Width	1.8°
Sampling rate	≤ 2Hz
Range	≤ 225 m
Range Precision	0.05 m
Tilt Sensor Range	20°
Tilt sensor accuracy/precision	0.5°/0.01°
Data Storage	64 Mbytes (standard), 128 Mbytes (optional)
Typical Deployment (standard battery pack)	40 weeks recording at 1 Hz.
Size	0.17 m (diameter)× 1.0 m
Shipping Weight	37 Kg

Remote Data Acquisition (i.e. non-real time) Mode

Measurements from a Mooring or Sea-Floor Platform in Moving Pack Ice

Profiling studies most commonly quantify: seasonal, year to year and short term changes in ice thickness; ice type distributions; ice ridge keel depths and the processes involved in ice deformations generated adjacent to structures and other obstacles to free ice movement. In most applications, quantitative knowledge of ice movement relative to the profiling sensors is required. For moored or sea-floor-based profilers, this knowledge is usually acquired from adjacent ADCP instruments. Such data allow conversion of draft time series into quasi-spatial representations (Figure 2) which offer realistic characterizations of offshore working/navigating environments including accurate, non-aliased ice draft statistics which allow tracking of longer term ice cover changes (See the plot of mean monthly ice thicknesses on the Beaufort Sea shelf for the years 1990-1998 (Figure 3)). Data from equivalently accurate moored profiling stations are likely to be an essential elements of future climate change monitoring in the polar regions.

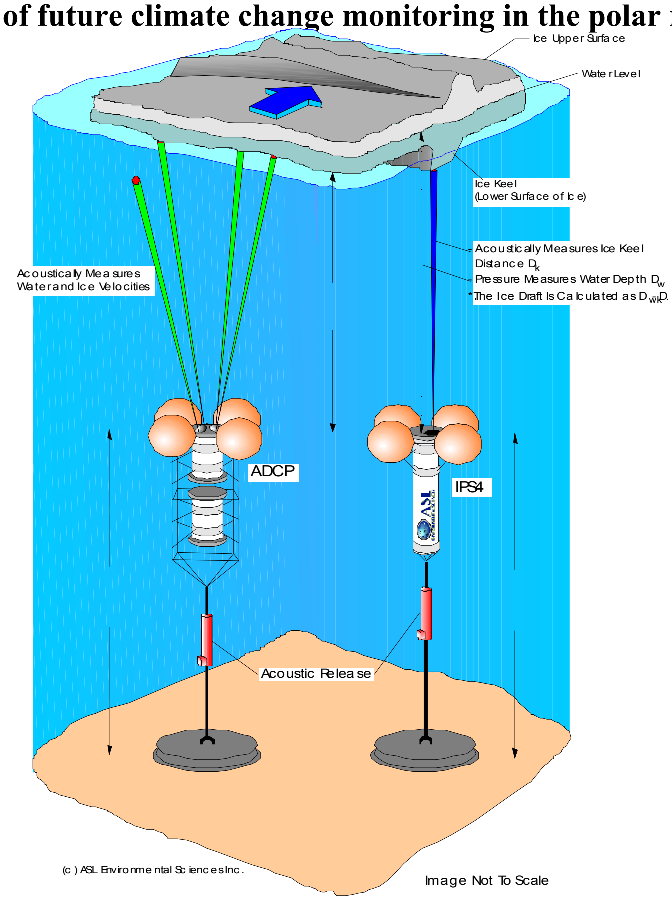

Figure 1. Schematic illustration of typical deployment of ice-profiling and ice-tracking ADCP instrumentation.

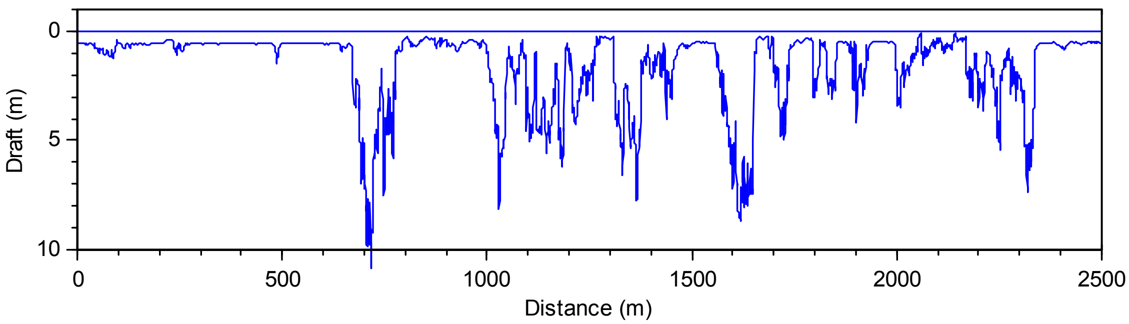

Figure 2. Quasi-Spatial Profile representation of ice draft data, gathered over the northeastern Sakhalin Island shelf, March 20, 1998.

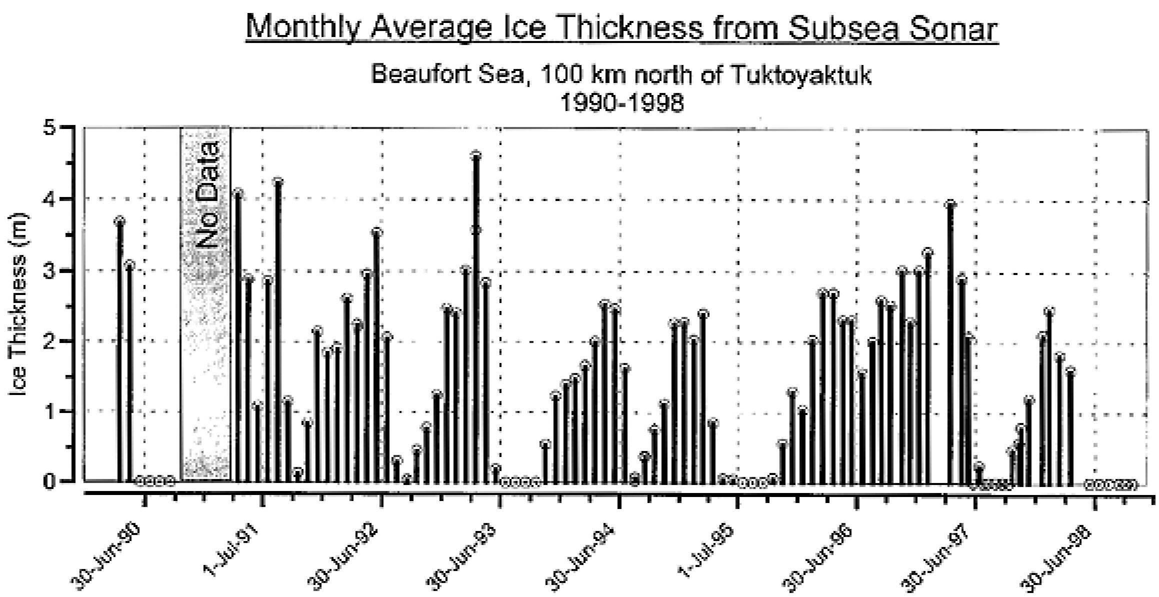

Figure 3.

The ***IPS-4's*** high sampling frequency has also facilitated acquisition of data on operationally-significant **intense wave activity** in thick pack ice well inside pack ice boundaries. The distinctive signatures of such waves are evident in the time series draft record of **Figure 4** recorded off Sakhalin Island during a March, 1998 cyclone. Wave amplitudes in 1.35 m thick ice at the outermost IPS-4 monitoring site, more than 300 km from open water, were in excess of 1m. The monochromatic nature of the wave disturbances is evident in the corresponding spectra of **Figure 5** where the waves can be seen to have been attenuated and red-shifted as they progressed shoreward through the ice cover.

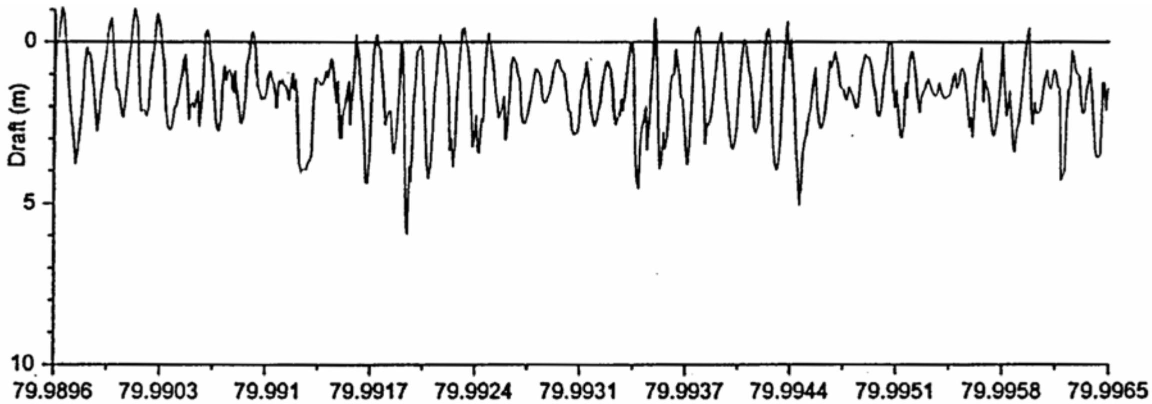

Figure 4. A ten minute segment of ice draft time series data gathered at the outermost Sakhalin site in ice of 1.35 m mean thickness. Time is expressed along the abscissa in fractional Julian days.

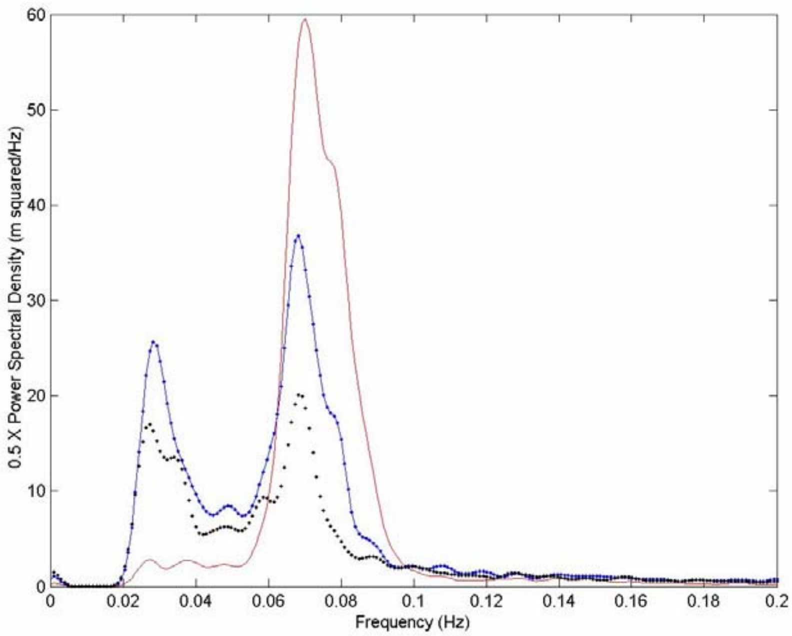

Figure 5.Temporal spectra for periods encompassing peak activity at three progressively more shoreward sites in the Sakhalin ice pack (solid line, outer site, more than 300 km from open water); (connected dots, middle site 18 km further inshore) and (unconnected dots, inshore site, 22 from outer site. 02:38-0712, March 21). High pass filtering previously applied to reject frequencies ≤ = 0.025 Hz.

Engineering-related profiling applications have, in recent years, included a major study (by oil industry interests and Fisheries and Oceans Canada) of ice forces and flow obstruction at supporting piers of the Confederation Bridge linking Nova Scotia and Prince Edward Island. Histograms of IPS-4 ice draft data obtained with IPS-4 units on opposite sides of a pier during corresponding periods of compressive pierward flow are shown in **Figure 6.**

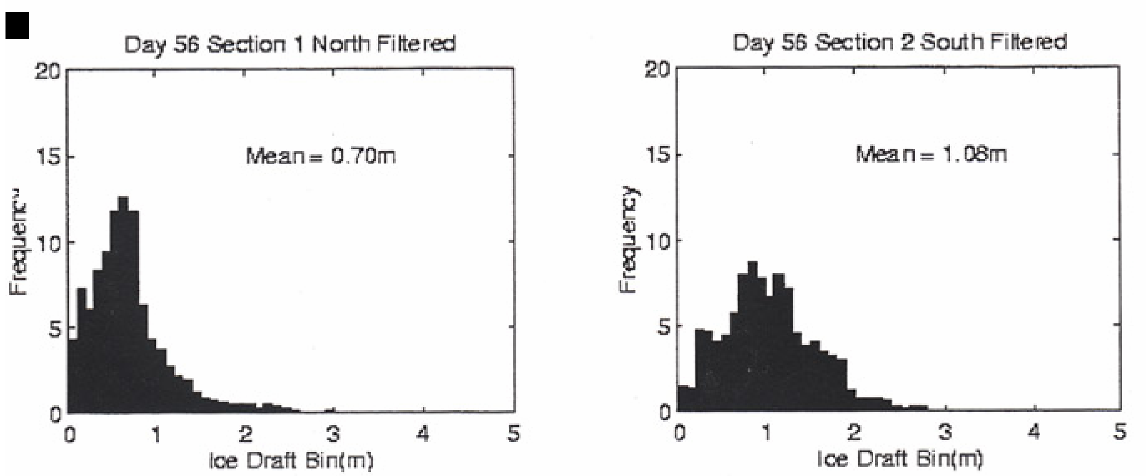

Figure 6. Histograms of ice draft recorded in 5 hour pierward flow periods on Feb. 25, 2000 on the opposite sides of the Confederation Bridge *(Beliveau et al., Proc. POAC '01, pp. 349-358)*.

An interesting feature of the Confederation Bridge results was the observation of consistent discrepancies between ice drafts derived from, alternatively, the IPS-4 and helicopter-borne electromagnetic impulse sensors. It was concluded that this discrepancy arose from the inability of the latter sensors to detect high salinity brash ice trapped or floating beneath the pack ice.

Real Time and Near-Real Time Mode Applications

River Ice Profiling by the Canadian Coast Guard

Data from an IPS-4/ADCP instrument pair in a critical channel of the St. Lawrence River is presently being transmitted real time through an RS422 interface and a radio link to the Quebec City SLRIM (St. Lawrence River Ice Manager) headquarters of the Canadian Coast Guard (CCG). Such data provide a key input to CCG activities which maintain winter navigability in the St. Lawrence Seaway and are distributed to authorized marine users via a website. An example plot of range data acquired during the 11:00-12:00 interval of December 13. 2001 shows a clearcut transition from the static conditions denoting an ice jam to the variable range record signifying the resumption of ice movement at approximately 11:23.

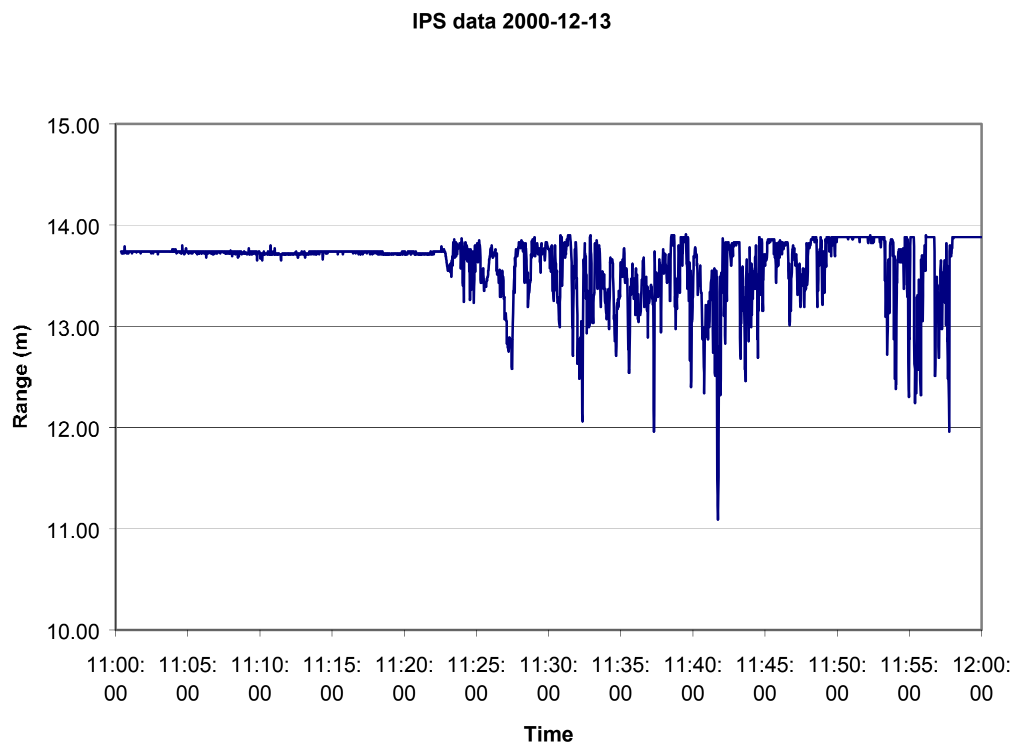

Figure 7. IPS-4 range data obtained in Lac St. Pierre, in the St. Lawrence River from 11:00 to 12:00 local time, Dec 13, 2001 (Data provided by L. Dupuis and S. Dumont, Canada Coast Guard).

Deployment on MBARI AUVs

Near-real time profiling capabilities have recently been demonstrated with the installation and successful testing in Arctic waters of a modified version of the real-time IPS-4 River profiling unit in an Autonomous Underwater Vehicle (AUV). The AUV in question has been developed by the Monterrey Bay Aquarium Institute (MBARI) to track intrusions of Atlantic water into the Arctic Basin. As deployed on the AUV **(Figure 8),** the role of the profiler is to both enable unattended, remote measurements of Arctic ice drafts (as a proposed alternative to, a now discontinued, SCICEX measurement program based upon U.S. submarines) and, more practically, to provide draft/thickness information for locating areas of thin ice suitable for periodic satellite data relay and communication functions.

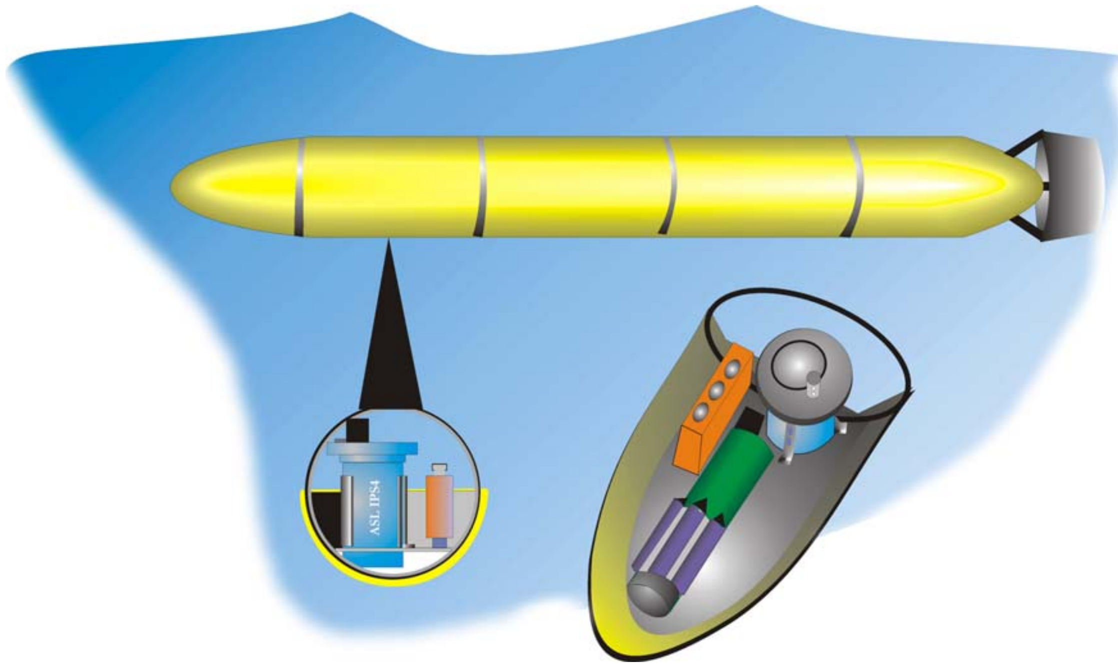

Figure 8. Deployment of an ASL Ice Profiler on the MBARI AUV (Adapted from Tervalon and Kirkwood, 2001; paper presented at Oceanology International Americas, 2001, Miami).

Reliability

The utility of remote profiling instrumentation in the above and other applications is highly dependent upon not only the accuracy and detail of the returned data but, as well, is closely tied to the reliability of data and instrument recoveries from, typically, hostile environments. In this respect, it is worth noting that worldwide recovery statistics for the IPS-4 are well over **90%** for both data and instruments. An example of present instrument ruggedness was recently provided by data collected in Antarctic waters by Dr. David Karl of the University of Hawaii's School of Oceanography and Earth Science and Technology.

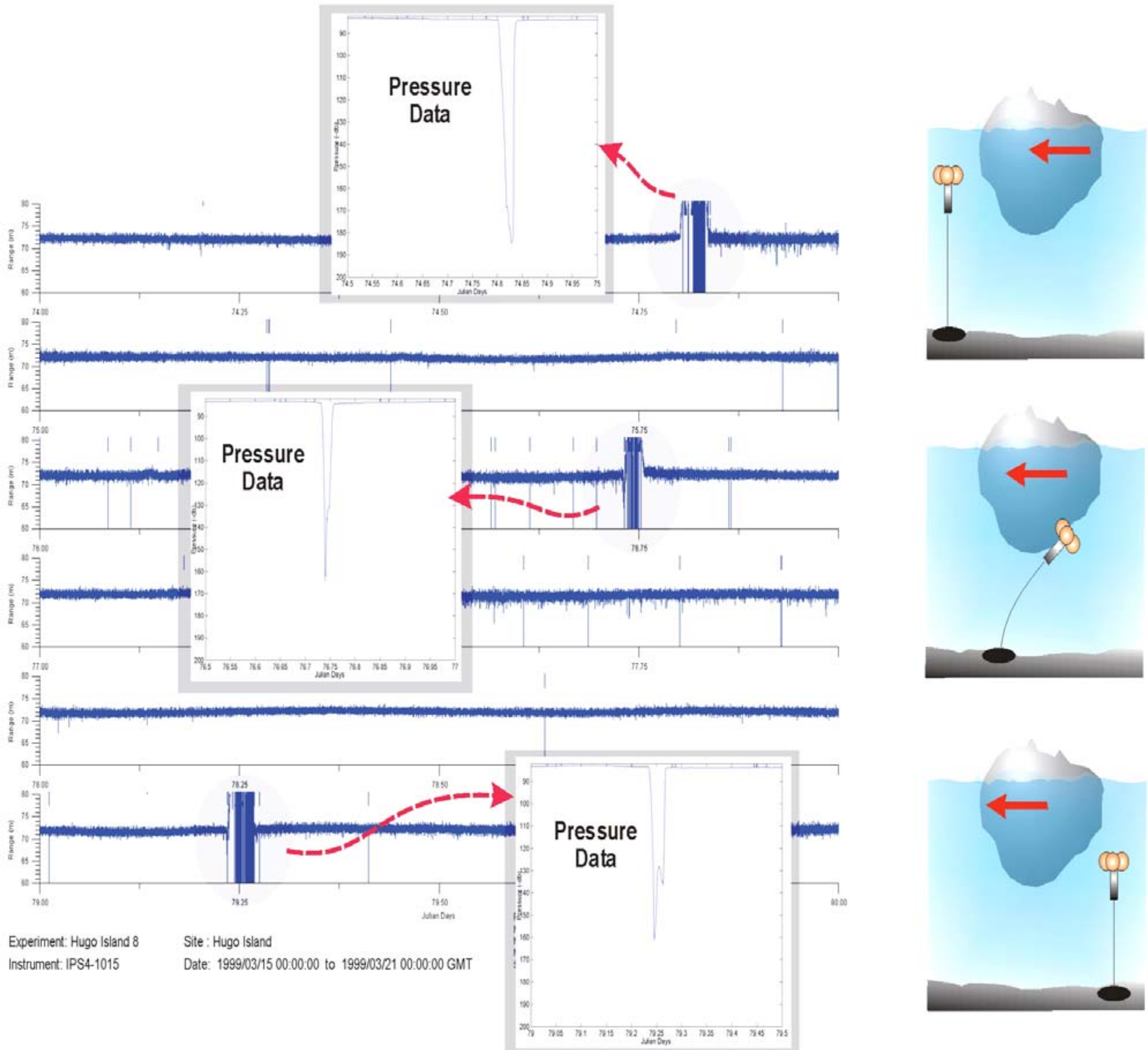

Figure 9. Range and pressure time series data recorded under Antarctic ice in the March 15-20, 1999 time interval (based upon data provided by D. Karl of the University of Hawaii).

As reproduced in **Figure 9,** the data of interest include 6 days of range time series accompanied by inserts of IPS-4 on-board pressure sensor readings recorded during the 3 highlighted range anomalies. (Several other such anomalies were recorded during the year-long instrument deployment.) The inserts show clearly the relatively sudden and massive increases in pressure and the eventual return to normal levels associated with depressions and re-ascents of the moored instrument which could only have been caused by the depicted collisions with drifting icebergs. The deepest displayed depression placed the IPS-4 unit more than 100 m below its 82 m deployment depth. The continued recording of range and all other data throughout these events and, in fact, for the full period of the deployment provides strong evidence that modern profiling technology is up to performing under even the worst conditions attainable in its naturally unfriendly working environment.

Conclusions

Technical and scientific advances of recent decades have now made it possible to obtain detailed data on ice-undersurface topography, -thickness and movements in both real- and non-real-time. Such data offer advantages of accuracy and cost relative to alternative methods of gathering similar data and, in many cases, provide ice cover information which was previously not practically accessible to the operational oceanography community.