Marine Ice Profiling: Future Directions

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ABSTRACT

Upward-looking sonars moored on the sea floor have contributed to our qualitative and quantitative understandings of ocean ice covers by enabling quasi-continuous measurements of ice draft along curvilinear tracks to accuracies as great as 0.05 m. The capabilities of ASL's own IPS4 instrument to acquire and store such data has been demonstrated in well over 100 deployments in polar and sub-polar ice-infested regions. Data obtained from these deployments has providing ice property and characterization information for platform and operations design, planning, navigation support and for scientific ice and climate studies.

Results obtained with recent use of the IPS4 and a sister instrument specialized to shallow water applications have motivated both the development of new deployment methodologies and suggested applications additional to simple ice draft measurements. Particular potential uses such as detecting unconsolidated ice content in lower portions of ice keels as well as the prevalence of loose and/or frazil ice under ice covers and in shallow water areas are discussed.

Perceived future needs in both conventional draft profiling and in these and other new applications are used to guide developing requirements for a new generation of IPS instrumentation offering new performance capabilities and additional user-specific configurability. ASL's vision of this instrumentation and progress toward prototype construction is described.

KEY WORDS: Ice draft and topography, frazil ice, ice consolidation, sea ice, river ice

INTRODUCTION

Beginning in the early 1990's with the pioneering development work of Humfrey Melling (Melling et al., 1995) in connection with long term Beaufort Sea studies, high sampling-frequency ice profiling instrumentation has become an essential tool in characterizing ice covers for the purposes of offshore development, climate-change study and basic scientific advancement.

In conjunction with upward-looking ADCP current profilers with ice movement tracking capabilities, ASL's IPS4 Ice Profiler has been widely used in all these respects to return time series measurements of ranges to the undersurfaces of moving ice covers. Such time series are readily convertible to "quasi-spatial" profiles which delineate ice draft as a function of linear distance along an ice cover. Typically, the Ice Profiler and the ADCP are deployed from adjacent or common moorings (Fig. 1). The accuracy and quality of the obtained data are critically dependent upon the high frequency (up to 2 Hz) at which the IPS4 measures ranges to the overlying ice and/or air/water interface surfaces and the narrowness (1.8º) of the angular footprint of its beam on these surfaces.

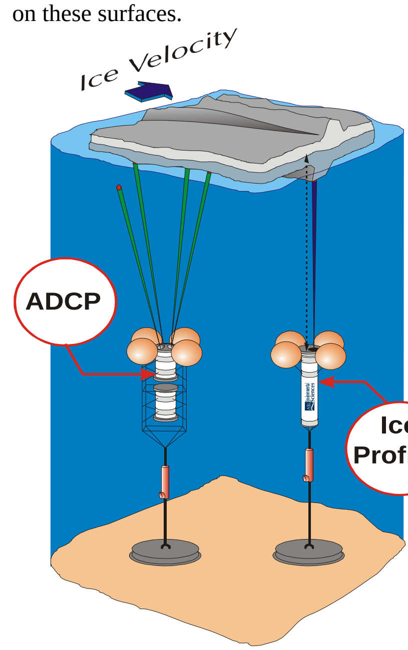


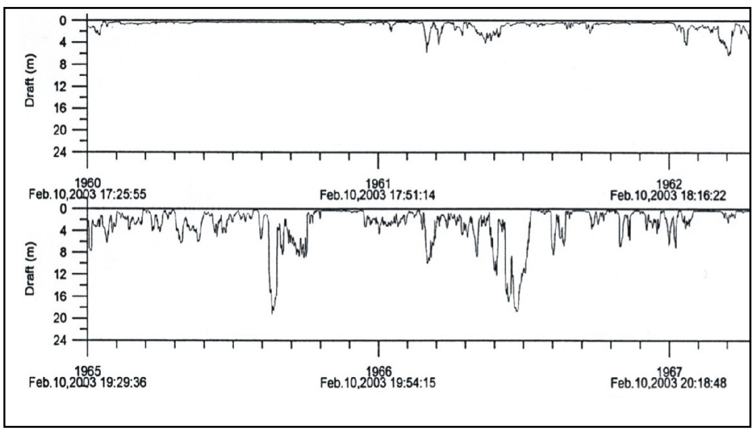
Fig. 1. A typical moored ULS Ice Profiler installation illustrating the single and quadruple beams of, respectively, the ASL IPS4 Ice profiler and ADCP instruments.

A very brief description is provided for the present instrument and measurement methodology, including an outline of the steps involved in the extraction of ice drafts from range information. Following comments on the history of past usage, results from recent deployments which appear to be relevant to further development of profiling platforms will be discussed. Our particular interests in this respect will focus on identifying additional flexibilities in deployment methodologies as well as new capabilities for extracting ice information which goes beyond simple profiles of the ice undersurface and draft statistics. This information is then used to identify desirable features of a new generation profiling instrument, the IPS5, which will eventually replace the IPS4 and offer users improved access to still better, more complete, information on ice and other components of the upper ocean and freshwater environments..

PRESENT ICE PROFILING CAPABILITIES

The IPS4 Ice Profiler[TM] depicted in Fig. 1 is a purpose-built acoustic sounder employing a narrow, 1.8°, high frequency (420 kHz) acoustic beam and rapid sampling (up to 2 Hz). It records high spatial resolution time series range data for the nearest (to the sonar sensor) portion of the ocean-ice interface. This information, combined with on-board recorded hydrostatic pressure and instrument tilt data as well as with regional-scale sea level atmospheric pressure data allows computation of time series representations of ice draft above the monitoring site. Ice drift velocity data gathered by the "bottom-tracking"-enabled ADCP unit allows conversion of draft time series into quasi-spatial profile products such as that represented in Fig. 2.

Fig.2. Quasi-spatial profiles of the underwater portions of the Sea of Okhotsk ice cover. Draft values are plotted as a function of



along track distance in km.

A critical feature of the IPS4 Ice Profiler is its high sampling rate which facilitates detection and accurate measurement of operationally and environmentally important features such as deep ridge keels. It also enables reliable processing and interpretation of data recorded in the presence of typical confounding factors such as bubble clouds, zooplankton concentrations and large amplitude ocean waves. This capability is dependent upon the IPS4's low power consumption which facilitates year-long or longer deployments and its high data storage capacity (69 and 138 Mbytes).

Accurate extraction of ice drafts requires intensive and careful processing efforts as outlined in Fig. 3 in terms of the linkages between measured ranges, r, the inferred acoustic sensor depth, η, and the ice draft, d. The key relationship in this draft extraction is:

$$d = \eta - \beta \cdot r \cdot \cos\theta, \qquad (1)$$

where β is a "to be determined" factor which accounts for changes over time in the mean sound speed in the upper water column and θ is the measured tilt angle of the IPS4 instrument. The acoustic sensor depth, η, itself, is established from the hydrostatic (bottom) pressure measured in the instrument, P_{btm} and the atmospheric pressure, P_{atm}, through:

$$\eta = (P_{btm} - P_{atm})/\rho g \ - \Delta D\ , \qquad (.2)$$

where ΔD is the physical separation in the vertical direction between the deployed acoustic and hydrostatic pressure sensors, and ρ and g, respectively, denote the density of sea water and the acceleration of gravity.

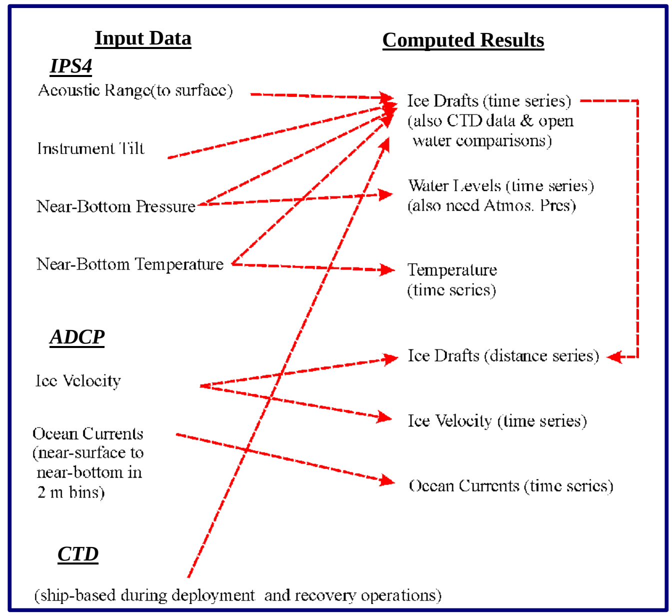


Fig. 3. Linkages between the various data sets collected at an Ice Profiler site and their usage in draft extraction.

The critical, accuracy-limiting factor in ice profiling is knowledge of the mean sound speed which is, usually, only available with accuracy over the full water column at the start and end of a deployment through direct CTD profile measurements and established relationships between sound speed and water property parameters. For intermediate times, speed estimates must be obtained as an integral part of the data processing/analysis program. This is done by establishing values of β which correctly yield zero draft values from Eq. 1 using range, r, and sensor depth, η, values from the nearest portion of the time series record corresponding to the unambiguous presence of open water above the IPS4 instrument.

EXISTING AND POTENTIAL APPLICATIONS: LIKELY NEEDS FOR INSTRUMENT AND METHODOLOGY IMPROVEMENTS

Over 100 separate deployments of IPS4 instruments at a wide variety of locations in both the Northern (Fig. 4) and Southern Hemispheres have been carried out to date, achieving an overall data recovery rate in excess of 95%. These deployments have clearly demonstrated the instrument's capabilities for developing ice draft statistics, quasi-spatial profile characterizations and acquiring wave and open water/ice fraction data directly relevant to design and use of offshore structures, marine navigation and to detecting and quantifying ice climate changes.

More recent developments of near-realtime shallow-water versions of the instrument have identified additional applications for under-ice profiling. These shallow-water instruments confine their power supply, control and processing electronics and data storage components to an adjacent shoreline module, thereby increasing data security, storage capacity and enabling near-realtime review of data and adjustment of measurement parameters. Shallow-water deployments have, in particular, demonstrated the value of data obtained in a true profiling mode whereby backscatter returns are recorded from individual, vertically adjacent, cells in the water column and inside floating ice layers. Deployments of these instruments in the Peace River of northern Alberta have shown (Jasek et al., 2005) capabilities for:

a) observing and quantifying concentrations of suspended frazil ice (Fig. 5) and

b) detecting differences in the strength and character of returns from "softer" and "harder" portions of a floating ice cover (Fig. 6).

In the first instance, Fig. 5 shows the diffuse, but highly time-variable, signatures of frazil ice throughout the water column. This particulate ice component is seen beneath the stronger (red) returns from an early season ice-infested river surface which, in the Figure, is seen to become progressively rougher with time, corresponding to gradual increases in the prevalence of ice floes on the river. Knowledge of the presence and properties of ice in the water column (e.g. its concentration and the size and vertical distributions of its constituent particles) is a key input to winter river management programs. Although ice in the water column is believed to be much less ubiquitous in salt water environments, quantitative data on its distribution and properties may be of use in marine climate studies and in certain ice management applications.

The data in Fig. 6 represent a time series of hourly-averaged intensity profiles associated with acoustic returns acquired following formation of a stable (immobile) ice cover. The plot shows the progressive (with time) thinning of the region of weaker (green) returns and the gradual advance of the region of stronger (red) returns closer to the lower boundary of the floating ice. The weak returns were associated with the "soft" (slush) ice which constitutes the lower and, initially, majority component of the stable seasonal river ice cover. The data in Fig. 6 document in detail the erosion of this component over the course of the ice season as the ice cover both thins and, overall, becomes converted into hard "thermal" ice. Further, although these measurements were made in fresh water, estimates of attenuation in the slush ice component yielded values which were very similar to those reported (Williams et al., 1992) in sea ice just above the skeletal layer. Although speculative, this similarity is at least suggestive of the possibility that, with sufficient power and sensitivity, profiling instrumentation operating at an appropriate frequency could extract information on the character of the lower portion of a sea ice cover above the skeletal layer. This information could provide a basis for semi-quantitative assessments of ice strength and consolidation.

Other potential benefits of routine acquisition and storage of water column acoustic amplitude data could arise in connection with zooplankton, phytoplankton, marine mammal and sediment monitoring programs.

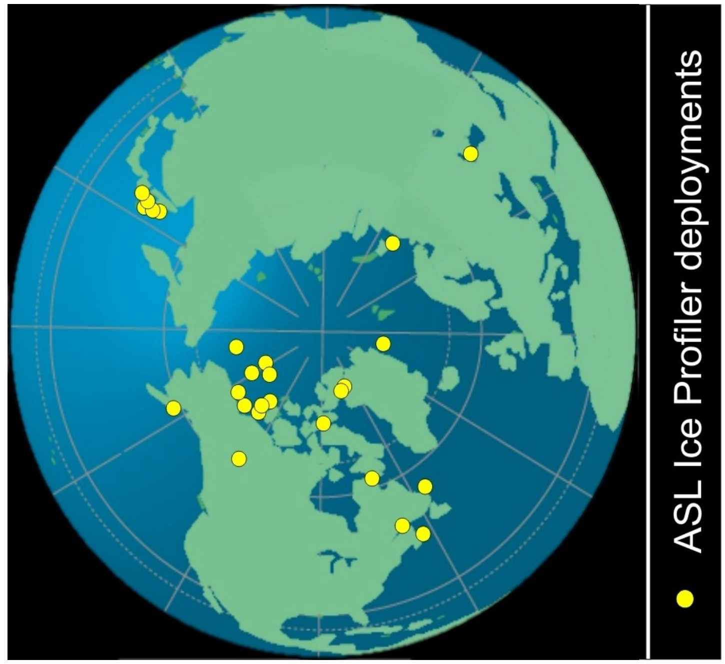


Fig. 4. Locations of ASL Ice Profiling application programs in the Northern Hemisphere.

All told, in-hand results support the potentially enhanced utility of a new, truly "profiling", generation of ice profiling platforms when employed in either conventional deep water or other (i.e. shallow water, on autonomous drifters etc.) applications.

Such an expansion of capabilities would not only allow extraction of additional useful ice cover data but would implicitly comply with a principal recommendation of a 2002 ACSYS (Arctic Climate System Study) Panel on moored sea ice draft measurements which called for inclusion of acoustic return amplitude data in the recorded output of future draft measuring instruments. This recommendation was directed at providing users with the additional means for enhancing the accuracy and reliability of the ice draft products derived from profiling instruments.

Beyond such advances in measurement capabilities, further development of ice profiling technology must address the fact that, while offering considerable cost and effort savings over alternative approaches to getting similar data, the logistical costs and risks of profiler deployments in remote polar and subpolar locations are still considerable. Full data utilization also still incurs the economic and labour costs associated with processing the large volumes of data which are recorded by such instruments.

In the latter respect, access to actual water column profile and amplitude data would be expected to ameliorate the considerable efforts involved in the critical sound speed recalibration step of the data processing program. Although some assistance in this respect is now available from point sound speed sensors mounted on the profiler, such recalibrations still usually involve detection and careful selection of intervals of open water and are essential to obtaining the draft accuracies in the 5-10 cm range demanded for some profiling applications. The subtleties of water surface recognition in terms of return signal amplitudes have been studied and discussed in detail by Melling (1998). Amplitude data from additional levels in the water column could only help to further simplify the surface identification process. True profiling capabilities which begin at user-specified ranges from the profiling transducer would make such data available for this purpose as well as for their own intrinsic value.

It is even more apparent that ease of instrument deployment and recovery and the user's degree of confidence in proper instrument functioning and robustness are important determinants of measurement program design and cost. To this end, ice profiling usage would be facilitated by instrument and methodological improvements which simplify and, if possible, minimize deployment/recovery operations.

Specific development possibilities are outlined below which address these needs, offering profiler users more efficient, economical data taking and enhanced data content and utility.

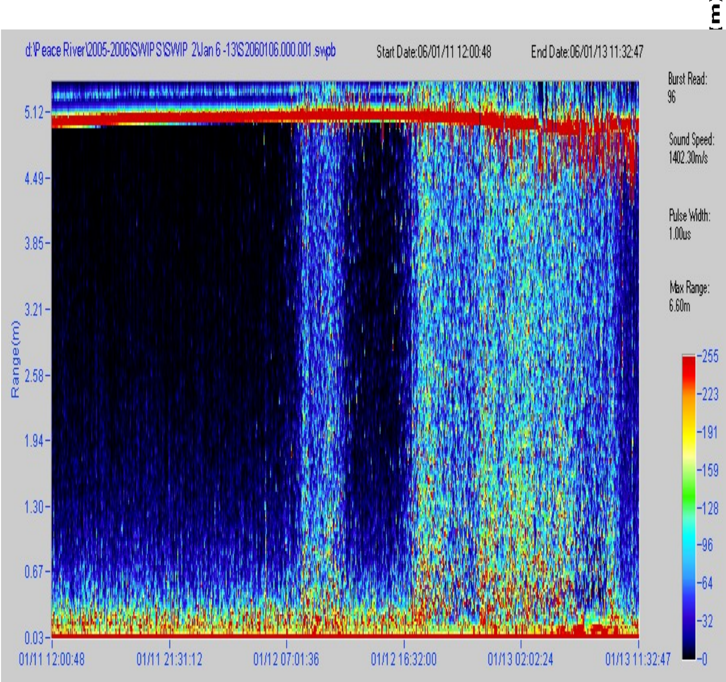


Fig. 5. Profile results show full range of amplitude variability in intervals associated with Frazil ice presence.

RECENT AND CONTEMPLATED IMPROVEMENTS

Deployment and Data Recovery

Assembly and deployment of two moorings at each monitoring/measurement site as indicated in Fig. 1 have typically involved either work on the ice cover surface, requiring aircraft support, or considerable labour and many hours of committed time from a large workboat operating at the deployment site either prior to the local arrival of ice or during brief intervals of ice clearance. However, recent efforts in the Sea of Okhotsk have achieved successful helicopter deployments of IPS4 and ADCP units mounted, in tandem, on the same individual moorings. These deployments did not require landings of aircraft or personnel on the ice or water surfaces. Instead, complete moorings were assembled onshore before being lifted and carried 10 to 20 km offshore (Fig. 7) for deployment in ice infested waters. In one instance, a mooring was dropped through a thin ice floe to its intended deployment depth.

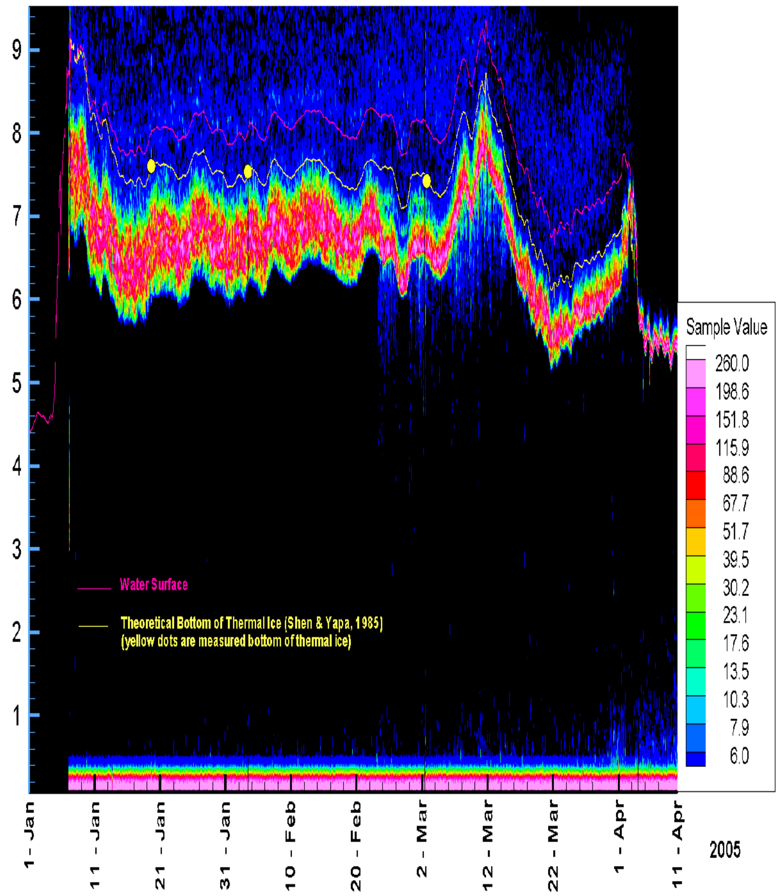


Fig. 6. Hourly profiles of return intensity as a function of range (in meters) for the stationary ice cover period (Jan. – Apr).including break-up on Apr. 3. Local water levels and modelled, and measured positions are given for the thermal ice undersurface.

Additional savings in cost, effort and anxiety could be achieved by lengthening the duration of Ice Profiler deployments. Such longer deployments would be particularly attractive if the deployed units included a capability for *in situ* downloading of data at convenient intervals such as during the annual ice clearances which occur at most deployment locations. At present, without degrading data utility by lowering the sampling rate, use of the present Flash memories and alkaline battery packs on IPS4 units allows at least 2 years worth of draft data recording with the addition of a second (external) battery-pack power supply. Still longer term deployments could be contemplated if the alkaline batteries on board the units are replaced by lithium cells.

In addition to motivating development of interim data downloading capabilities, longer duration deployments are likely to encourage other instrument design/composition changes which further increase probabilities for continuity of instrument performance. Obvious additions, here, include incorporating instrument tools which provide positive confirmation of instrument functioning prior to abandonment of the deployment site and, if possible, prior to release of physical contact with the mooring. Minimization of corrosion on external instrument and mooring components will become even more important than it is at present.

It is also reasonable to anticipate incorporation of profiling instrumentation in Polar Ocean observatory systems which are presently being planned. Such systems would operate in continuous or quasi-continuous data acquisition modes to provide realtime output over periods of 5 years or longer. Power would be supplied through the observatory cable. Key features of incorporated profilers would have to be realtime access and control over measurement parameters (to allow adjustment of measurement protocols in accord with observations) and high corrosion resistance of all "wet" components.

Fig. 7. Helicopter-borne deployment of an IPS4 +ADCP mooring (BP Ltd. Photo).

TOWARD A NEW PROFILER

As a first step toward achieving the above-outlined advances and new capabilities, ASL Environmental Sciences Inc. has initiated design and construction of a new digital processor and sounder unit which will be the principal platform for the Company's new generation of Ice Profiling and Water Column Profiling (WCP) instruments. When utilized in an IPS5 Ice Profiler, this platform would be intended to facilitate operations in a variety of configurations, selectable by the user, which allow addressing some or all of the data security and access and additional information needs discussed above.

Given those discussions, it has been determined that the processing portion of the new platform should:

a) be compatible with operations at power consumption levels lower than or equivalent to those of the current IPS4 processor.

b) support data storage well beyond the 138 Mbyte capacity of the present IPS4 unit;

c) support several communication interfaces with optional isolation;

d) offer its own realtime clock and data compression facilities

e) Replace the 8-bit capacity of the IPS4 with 12 or 16 bit data acquisition.

Additionally, for extended deployment durations of a few to several years, the IPS5 will be available in non-corrosive plastic pressure cases.

The upgrading of the data acquisition capabilities will both lessen processing reliance on TVG (time varying gain) and allow additional flexibility in increasing data storage capacity to support both longer deployments and acquisition of additional details on the measured environment when such details are of interest to the user. As noted above, details such as the amplitudes of returns from ranges both above and below the actual ice/water can increase the accuracy of the extracted draft values and/or provide additional documentation of the content and character of the water column and the lower ice cover. The data storage capacities of at least 4 Gbytes, likely to be offered in new generation units on extractable Flash memory cards, would allow on-board retention of these additional data although, in many applications, true profiling might be expected to be carried out with a less than 100% duty cycle..

The low power consumption sounder package would, as before, operate at a single, fixed, frequency with a low noise front end. Reliability remains critically important for all considered applications. Consequently, the unit would include an (optional) facility designed to give either a visual or other (acoustic) indication of proper functioning (i.e. transmission and reception of return "pings" as well as checks on basic steps in processing and data storage). Ideally, in accord with the above performance requirements, the unit should be able to both confirm such functioning prior to physical release and include the present unit's capability for restarting itself should its operations, for some reason, be interrupted after deployment.

The unit's communication links are to be configured to be compatible with an (optional) facility for externally-triggered communication of data through an acoustic modem link. This facility would be intended to allow a manageable portion of the most critical on-board stored data to be downloaded in the open water season without recovery of the moored instrumentation. Acoustic modems operating at 9800 baud or faster could presently use such links to enable interim access to data for early processing and review and/or for full confirmation of proper data collection operations. In principle, such downloading should be feasible at most sites at intervals during long term deployments. This facility, at the cost of a few hours of small vessel time, could considerably shorten the times involved in getting initial access to local profile data and lessen concerns regarding instrument and data quality and security. It is also feasible that the downloading facility, itself, could be used to perform the instrument operations verification function outlined above.

Finally, ASL is now finalizing design and fabrication of a plastic pressure case which should address any corrosion problems which might arise during longer term deployments.

Present plans are to initiate field testing of a IPS5 prototype during the winter of 2006-2007 with the new instrument being available to users for the winter of 2007-2008..

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