# Ice Profiling Sonar for an AUV:
# An approach for obtaining SCICEX quality ice draft data

Nicole Tervalon
tervalon@mbari.org

William Kirkwood
kiwi@mbari.org

Monterey Bay Aquarium Research Institute (MBARI)
7700 Sandholdt Road, Moss Landing, CA 95039

## ABSTRACT

The United States Navy announced plans to eliminate the Sturgeon class submarine fleet some years ago. Since then a discussion has continued about the availability of other Navy assets to continue the SCICEX cruises used for measuring and monitoring Arctic oceanographic properties including ice draft. This is of particular importance at this time, since recent studies indicate the ice cap may be disappearing at an alarming rate, and its important relationship with global climate is becoming more and more evident. The Navy is expecting to ice harden two submarines of another class, but scientific access is still an unresolved issue.

Addressing this problem for science requires a platform with proven capability that can provide comparable data. Ultimately the goal is to provide the services science wants, and to replace the lost usage of the U.S. submarine assets. With the development of proper navigation and attitude reference systems capable of accurate performance in the Arctic, this should be possible using an autonomous underwater vehicle (AUV).

This paper will address proposed efforts at MBARI looking to integrate an ice sonar into an AUV and using it to perform SCICEX quality ice draft measurements in the Arctic Ocean. The equipment necessary to integrate an ice profiling sonar into an AUV system is not extensive because one can take advantage of the many sensors already incorporated into a basic AUV that are used primarily for navigation and basic science (such as the CTD). The most important aspects of the integration are first, the physical limitations in size and weight of the system, and second, proper assessment and coalescence of the necessary physical measurements which, unlike in a moored application, are spread throughout the vehicle. The discussion will further outline the expected system requirements and equipment tolerances that will be needed to be successful. It will additionally describe the experiment planned to test the system against its functional requirements in the Arctic.

## INTRODUCTION

The physical oceanography of the Arctic Basin and its influence on and response to climate change have become very important topics in the last decade (Steele and Boyd, 1998; Dickson, 1999). Studies have been carried out from ice camps, icebreakers, satellites and aircraft, moored and drifting buoys, and naval submarines. The submarines provided a much more flexible platform than previously available for scientific observation under the ice cover. These submarine assets made available to the science community are from numerous countries, and those offered through the United States Navy in the 1990's became part of project known as the SCICEX Program. The data resulting from this collaboration between the academic institutions and the Navy has been substantial (Rothrock et al., 1998). Unfortunately, now that the SCICEX Program has ended, the US submarines are no longer available to the community, and prospects for their future use are slim.

Long tracklength measurements of ice draft are one of the unique capabilities the submarine platforms provided. Except for the SCICEX cruises, submarine ice draft measurements have had limited spatial and temporal resolution and have been difficult to obtain at all, in many circumstances, due to the sensitive nature of submarine missions in the Arctic Ocean (Bourke and Garrett, 1987). It has been determined, however, that continued, large-scale monitoring of the ice draft over the Arctic basin is vital to improving our understanding of the role that the Arctic plays in the larger picture of global climate (McLaren et al., 1992; Wadhams, 1990).

A new tool being developed at the Monterey Bay Aquarium Research Institute in collaboration with a number of other institutions and industry partners will be capable of long duration autonomous under ice scientific missions (Bellingham et al., 2000). As part of the Atlantic Layer Tracking Experiment (ALTEX), this AUV is scheduled for its first Arctic engineering test in Fall of 2001. Given the ability of the vehicle to remain under the ice for up to ten days and traverse up to 1500 kilometers underwater, it is an ideal platform candidate for continuing the measurements and monitoring of ice draft. It has been decided, therefore, to outfit this platform with an ice profiling sonar capable of scientific quality ice draft measurements. Adding this tool to the ALTEX vehicle sensor package is beneficial for another reason, as well. It can be used to locate appropriate launch locations for the data transfer buoys used to transmit vehicle data via ARGOS.

The objectives of this project are to demonstrate the functional ability of a long duration Arctic-capable AUV to measure ice draft, and to further assess its usefulness as a platform for performing unique Arctic science. This work is based on using the equipment and vehicle platform of the ALTEX program.

Specifically, we would like to

1. determine how accurately an AUV can obtain ice draft measurements, where ice draft is defined as the distance from the bottom of the ice to the mean surface water level
2. to collect up to four 50 km data sets of ice draft measurements
3. to compare the quality of the results of these measurements with those historically collected by other available platforms – specifically those collected by submarines as part of the SCICEX cruises

This paper will give a brief background on under-ice measurement platforms and the autonomous underwater vehicle (AUV) development occurring at MBARI. It will then present the system requirements and explain the selection of the system that is to be used. It will also describe both the physical and systematic integration plans for the system, a description of the Arctic test plan, and finally it will conclude with a number of suggested science applications.

## BACKGROUND

### *Under-ice measurement platforms*

Ice draft is defined as the distance from the bottom of the ice to the mean surface water level, and ice thickness is the total distance from the bottom to the top of the ice surface. Three current platforms are capable of measuring ice draft from under the ice surface: submarines, moorings, and autonomous underwater vehicles. They all use acoustic methods that measure the time it takes for a narrow beam acoustic burst to bounce off the underside of the ice and return to an acoustic hydrophone. This information, coupled with knowledge of the speed of sound in the water column, allows one to determine the distance to the bottom of the ice. The mean water level is generally determined using a pressure sensor and is appropriately adjusted using knowledge of the atmospheric pressure at the water surface. Additional pieces of information necessary to make these measurements accurately are the attitude of the measurement platform and its position. A typical ice sonar system includes all the instrumentation necessary to acquire the above mentioned measurements. For a mooring, all the sensors are integrated in the platform and approximations are made between the time of deployment and recovery about the speed of sound profile and the ambient atmospheric pressure. On a submarine, the acoustic time-of-flight is measured by on-board acoustic systems and then combined with other water mass measurements collected during the mission to generate the ice draft estimate. AUVs offer a smaller, and generally less complex system than is found on a submarine. It should be noted, however, that very few AUVs are currently capable of providing high quality ice draft data. For scientific use, the overall accuracy of any proposed ice draft measurement system needs to be 10 cm or better in order to compare with current accuracy levels obtainable by scientifically available post processed submarine and mooring data (Rothrock, personal communication).

### *AUV development at MBARI*

MBARI is currently developing a new autonomous vehicle under the ALTEX program. The ALTEX experiment is an acronym for Atlantic Layer Tracking Experiment, which is intended to track the Atlantic layer of water intruding into the Arctic Basin and monitor some of the effects that water mass is having on the Arctic Ocean. ALTEX is a joint program involving the efforts of several partners and is dedicated to creating a long-range vehicle for science in the arctic. The ALTEX development effort provides a vehicle capable of 1500 kilometers of travel under the ice and high latitude navigation. Figure 1 shows the full length ALTEX vehicle. The new vehicle platform, referred to as Dorado at MBARI, is also intended to create a modular system that will provide flexible platform for years to come for both Arctic and non-Arctic missions. MBARI is already proceeding with vehicle development of an acoustic survey payload module capable of highly accurate sea floor surveys (reference these proceedings - Caress and Kirkwood, High Resolution Mapping with AUVs)

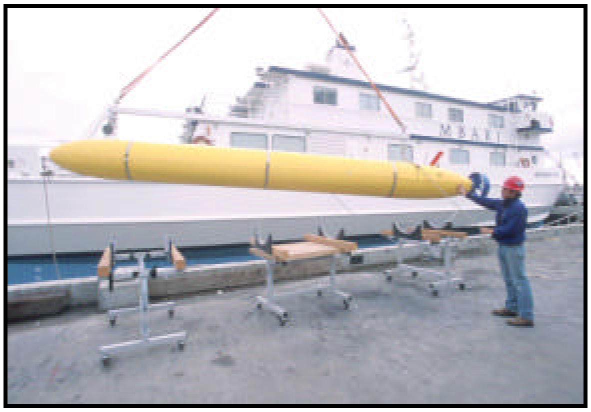

**Figure 1: ALTEX AUV being prepared for at-sea trials**

The Dorado design approach is to use pressure tolerant sub-systems to the greatest extent possible. The new vehicle is controlled through an articulated tail section with a ducted propeller called the tailcone. The tailcone offers several advantages over the more traditional fins used for control. First, the system keeps the control surfaces within the 21-inch diameter of the vehicle. Second, the surface is a continuous ring and less prone to damage during launch and recovery. Two key elements are being developed as part of the ALTEX configuration that allow for long duration under-ice missions. The two sub-systems are a pressure-tolerant fuel cell and a payload of buoys that can melt through the ice to communicate through ARGOS satellites.

The fuel cell being developed is pressure compensated to accomplish the deep-ocean rating. The fuel cell section contains an aluminum oxide chemistry to produce 66 kWh of net energy. The section is neutrally buoyant and fits in a 21 inch diameter hull section. The fuel cell is 66 inches long and will provide enough power to run the AUV at 3 knots for 200 plus hours with a limited science payload. The liquid reactants are low cost and significant portions of the cell stack are re-useable making the total cost low over multiple runs.

Data is transmitted from the vehicle by 12 buoys, launched individually from the vehicle that melt through the ice and transmit subsets of data via ARGOS. The AUV downloads the data into the selected buoy, and then searches for a section of ice thin enough for the buoy to successfully melt through. The AUV maintains a depth of approximately 50-meters to avoid obstacles such as ice keel and attempts to locate a suitable launch site. Once a site is located the launcher is instructed to release the selected buoy. After being released, the buoy reaches the surface of the ice, melts through the ice, then a balloon is inflated containing a GPS and an ARGOS antennae. Using a predictive algorithm for likely ARGOS communications, the buoy obtains a GPS fix, and initiates its data telemetry.

Engineering tests in the Arctic are scheduled for Fall 2001. Plans include an endurance test of two days to prove the system for the ALTEX mission. During this engineering test cruise, the experiment outlined in this document will also be supported.

## SYSTEM REQUIREMENTS AND SONAR SELECTION

The basic measurements needed to generate an ice draft estimate are not difficult to obtain underwater, even from an AUV. It was decided, however, that developing a system from the ground-up that would meet the scheduling deadline for the Fall 2001 test cruise was not feasible. As a result, we undertook a search for existing systems, or those that could be simply modified, which would meet our objectives. The functional requirements listed below were assembled to meet both the science needs and the somewhat rigorous demands for integration into the MBARI AUV.

- *Accuracy of the ice draft measurement*: at least +/- 5 cm for post-processed data collected at 50m depth; at least +/- 30 cm for underway calculations of ice draft collected at 50m depth
- *Working depth of instrument*: down to 100m, average depth of use 50m
- *Survivable depth*: 165m (upgrade to 4500m in future)
- *Pressure transducer*: highest sensitivity possible and still capable of surviving to 165m
- *Tilt sensor*: minimum accuracy of 1 degree measured in two dimensions
- *Acoustic head and electronics packaging*: transducer and electronics pressure housing for the instrument need to have a volume less than 1 $ft^3$ and have the largest dimension be less than 21 inches
- *Power*: external power at a voltage level of 5, 12, or 24 V will be provided to a wet connector on the pressure housing; the instrument must also have the ability to be toggled in and out of a standby/low-power mode via a serial command; total power consumption sampling at 1 Hz must be less than 1 Watt
- *Data storage and output*: the instrument should store data locally (at up to 1 Hz sampling rate for up to 10 days), but also be able to send ASCII formatted data packets containing all relevant

sensor parameters through the serial port either streaming or when polled

- *Communications protocol*: RS-232
- *Software*: software should be provided which will run on the MBARI AUV main vehicle computer to calculate ice draft from the ice sonar instrument's data output, a temperature and conductivity vertical profile of the water column, and an estimate of atmospheric pressure
- *External sensors*: conductivity and temperature will be collected by external independent sensors located near the ice sonar, atmospheric pressure will be estimated prior to vehicle launch and stored on the AUV

## MECHANICAL AND ELECTRICAL INTEGRATION

Based on a survey of products available, it was decided to purchase and modify the Ice Profiler™ commercially available from ASL Environmental Sciences Inc. The Ice Profiler acoustic and electronics housing measures 25.4 cm (10.0 in) in diameter at its widest point, and 41.4 cm (16.3 in) in overall height as shown in Figure 2. It will be located at the aft end of the modular nose section of the AUV as shown in Figure 3. It will be rigidly affixed to a mounting plate that is fastened to the AUV hull internal structure.

**Figure 2: ASL Environmental Sciences Ice Profiler system remote acoustic head and electronics housing.**

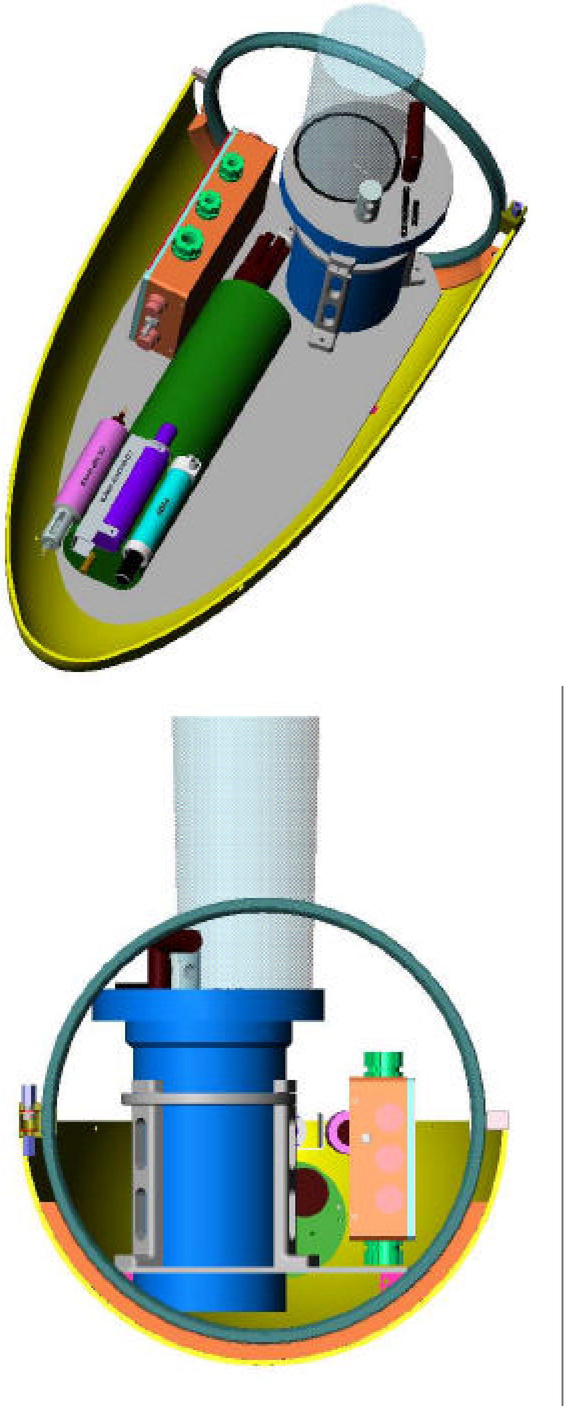

**Figure 3: Isometric and side view of Ice Profiler as it will be mounted in the AUV nose section. The transparent cylinder represents the field-of-view of the sonar. Included in the image are a few of the science sensors and the electronics junction box.**

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™ Ice Profiler is a trademark of ASL Environmental Sciences Inc.

The transducer head is an integral part of the endcap of the acoustic and electronics housing of the Ice Profiler. Both the pressure sensor cage, and power and communications interface cable also protrude from this endcap. As a result, the endcap is very hydrodynamically draggy. Furthermore, in an ideal world, the acoustic transducer would have an unobstructed view of the ice. Due to the endcap design and the high hydrodynamic drag incurred by a large hole in the AUV hull that would be necessary to locate the endcap out of the flow and within the AUV, it was decided to require the system to operate through the hull. It is expected that the ABS fairing, which has a density very near that of seawater, will have a negligible impact on the acoustic integrity of the 420 kHz sonar system.

The power and communications cable will be routed into a junction box that distributes regulated power and contains access to the vehicle communications bus.

## SYSTEMATIC INTEGRATION

The ASL Ice Profiler collects and logs data internally. This data consists of time and date, pressure, travel time of the acoustic ping, tilt of the sensor, and other indirect measurements used to improve the system's ability to estimate the ice draft when post-processing and analyzing the data. This constitutes the standard configuration for their moored system. In order for the sonar to be used as effectively as possible aboard the MBARI AUV, a number of modifications are being made to the standard ASL Ice Profiler system, and additional software is being developed. The hardware and firmware modifications being implemented by ASL are associated with the requirement that the system stream real-time data out of its serial port. This is required in order to allow the AUV to estimate ice thickness while underway. This is useful for many applications, but for the ALTEX mission specifically, this capability will allow the vehicle to locate an appropriate thin patch of ice through which to launch its data buoys. In addition to the real-time data output from the sonar system, there must exist software onboard the AUV that will take this raw sensor data stream and generate an estimate of ice thickness from it. ASL will be providing this piece of code, which will be referred to as the ice draft function. It will be based on algorithms from their already well developed post-processing software package.

In order to estimate ice thickness with the highest accuracy possible while the vehicle is underway, the ice draft function needs two additional pieces of information: the sound speed profile of the water column and the atmospheric pressure. The atmospheric pressure is needed because the onboard pressure sensors measures absolute pressure, not gauge pressure. The sound speed profile of the water column is necessary to appropriately interpret the travel time of the acoustic ping and turn it into an accurate distance to the bottom side of the ice.

The atmospheric pressure cannot be directly measured during the course of an ice profiling mission because the AUV will not be programmed to visit the sea surface in any open water leads it may find for safety reasons. The AUV will, therefore, only have one actual measurement of the atmospheric pressure that it will have collected at the time of its launch. Any ice thickness estimates made by the ice draft function will be increasingly erroneous if this single pressure value is always used, because the atmospheric pressure changes over time. To minimize this error, a prediction file will be used. This will be increasingly important for multi-day missions. This file will be generated from the launch ship's weather monitoring systems and will contain a prediction of the atmospheric pressure over the course of the AUV mission. It will be stored onboard the AUV prior to launch.

A sound speed profile of the water column will be calculated from sensor data collected on the upward portion of a yo-yo behavior. This behavior will be run at the beginning of each ice profiling mission, and also periodically during the mission, if the mission is longer than 6 hours. The yo-yo behavior will send the vehicle down to at least 300 meters, or to within 20 meters of the bottom, whichever is shallower, and then record the conductivity and temperature as a function of depth while the vehicle returns to its standard running depth under the ice. The sound speed profile will need to be estimated between the running depth of the vehicle and the actual underside of the ice, but with the deeper water conductivity and temperature profile, it is expected that the resulting shallow water interpolation will be a reasonable approximation. For the Arctic test cruise this year, the depth of the water column profile will be lessened to accommodate the depth limitations of the Ice Profiler.

While estimating ice thickness in real-time will be beneficial for certain AUV activities, post-processing the data after a mission is complete will generate the most accurate measurements of ice draft. This is primarily due to the additional information available after a mission (such as actual atmospheric pressure), as well as the often non-deterministic statistical calculations used to process the sonar data. There will also be the opportunity to further correlate and compare the various other sensors used aboard the AUV with sensors in the Ice Profiler package. For instance, the Ice Profiler system will retain its own tilt sensors, but the AUV has attitude sensors used for its navigation that could possibly be used instead. A key aspect of the testing of this system onboard the AUV is determining which sensors already incorporated in the vehicle can replace those typically packaged in the stand-alone sonar system.

## ARCTIC TEST PLAN

All of the AUV testing will take place off of the US Coast Guard Icebreaker Healy. This is the vessel from which the ALTEX program engineering tests will be conducted. The test plan will center around an intensive local survey of an ice covered area 2.5 km by 2.5 km, as well as a series of 50 km long single line surveys. The local survey will be collected while the AUV is flying straight and level legs at a depth of 50 meters, and will allow repeated measurements of the same ice field by the AUV to determine the repeatability of the system. The ice area surveyed by the AUV will also be cored at regular intervals to determine the system accuracy. The ideal site for the local survey would be an ice field with relatively new ice, but with some non-uniform features, and would have an open water lead or polynya within it. The long single line surveys will be used for statistical comparison with submarine ice profiling track lines, which are typically segmented into 50 km lengths (reference). The CTD measurements collected by the vehicle and resulting speed of sound calculations will need to be validated as well. To accomplish this a series of CTD casts will be collected during the local survey. It is expected that the outlined testing can be accomplished in 4 days, which includes 1.5 days of contingency time.

Since the AUV will be equipped with the Ice Profiler during all of its other engineering tests, it is recommended that the system be enabled and collecting data during those times. The additional data can be used for further analysis beyond the scope of the short experiment outlined above. Specifically, during the test missions that will perform yo-yo like behaviors to sample water column properties, it would be beneficial to assess whether the system is concurrently capable of measuring ice draft.

## SCIENCE APPLICATIONS

AUVs have already been successful as tools for understand biology, physical oceanography, chemistry, and are expanding into all other aspects of ocean science. Some of the concepts being discussed are adaptive vehicle behaviors based on pre-set science parameters. This would include things like following frontal systems, mapping biomasses, or tracing any number of parameters that can be mixed and matched as topics of interest. Often this course of action requires the development of new sensors, but many existing sensors can be modified and used for new science applications aboard AUVs.

With the generalizations outlined above, the same applies to the sensors carried on AUVs. The question becomes, how can the Ice Profiler be exploited for science in other areas or in other unique ways? While most of the ideas presented are not difficult to imagine, the impact could be very valuable to a wide community of science.

The first application expansion that MBARI has considered is the adaptation of the Ice Profiler to finding thin ice. The new Ice Profiler offers some exciting opportunities in this area. The ALTEX experiment requires finding thin ice to successfully launch and transmit data, but this in turn requires measuring the ice draft. Prior to the Ice Profiler, the available instruments on the AUV required finding thin ice with a bias offset to account for lack of accuracy. The resulting issues are that many possible launch sites are eliminated due to uncertainty. The increased accuracy of the Ice Profiler, therefore, would greatly increase the amount of area available to launch. The Ice Profiler is not rated deep enough for the ALTEX experiment as yet, but MBARI and ASL can see the possibility of an upgraded version for deeper ratings.

Another application is to characterize the ice floes and fields. With the capabilities of the AUV and its instrument payload, the ice sonar can collect detailed draft measurements while traversing a planned path. This would yield a sub-surface pattern of keels, and roughness characteristics. Using the acoustic Doppler velocimeter log (DVL), the AUV can also give information about the ice floe velocities and spatial orientations. The water column and near-ice chemistry, sampled by other sensors aboard the vehicle, may also be characterized as the AUV yo-yos in the prescribed area.

Yet another possible application is the tracking and gathering of detailed data sets regarding leads in the ice field. Here the AUV and Ice Profiler combination can give details about the opening and translation of leads in the ice. Real-time low cost data sets can be collected regarding the formation and eventual closure of the leads during ice floes. Using known techniques, lead locations could be communicated to ice breakers, scientists, or correlated to other data sets depending on the user needs.

These are just a few examples of Ice Profiler applications that are possible. With further discussion in the science community, MBARI hopes to find the compelling science to take on one or more of these challenges and further the use of AUV instrumentation in the Arctic.

## ACKNOWLEDGEMENTS

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