Field Results for an Arctic AUV Designed for Characterizing Circulation and Ice Thickness

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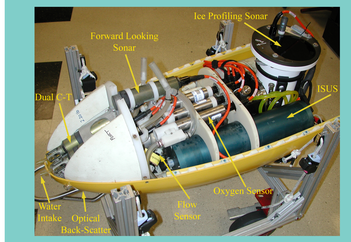
Abstract

An Autonomous Underwater Vehicle designed for operation at high latitudes and under ice completed its first Arctic field tests from the USCGC Healy in fall of 2001. The Atlantic Layer Tracking Experiment (ALTEX) AUV has been under development since 1998, and is being created to provide: unprecedented endurance, ability to navigate at high latitudes, a depth rating of 1500 to 4500 meters depending on payload, and the capability to relay data through the ice to satellites via data buoys. The AUV's initial applications are focused on tracking the warm Atlantic Layer inflow - the primary source of seawater to the Arctic Ocean. Consequently the primary payloads are twin pumped CTD systems. Oxygen and nitrate sensors provide the ability to use NO as a tracer. An ice profiling sonar allows the AUV to estimate the ice thickness in real-time and is designed to generate high quality post-processed ice draft data comparable to that collected through the SCICEX program. The experiments in October aboard the USCGC Healy generated numerous water column and under-ice data sets. Traditional ship-based CTD operations were used to provide a comparison data set for AUV water column measurements. The post-processed ice draft results show reasonable ice profiles and have the potential, when combined with other science data collected, to shed some additional light on upper water column processes in ice-covered regions. Cruise results include: operating the AUV from the USCGC Healy in the ice pack, demonstrating inertial navigation system performance, obtaining oceanographic sections with the AUV, obtaining ice draft measurements with an AUV born sonar, and testing the data-buoy system.

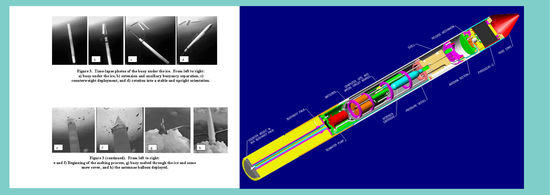
Introduction

A modular vehicle has been designed and tested. The design employs four functional sections: a forward payload section, the buoy section, the power section, and the tail section that contains propulsion, guidance, and control systems. The vehicle is designed to allow 'mix and match' vehicle sections, and a variety of power and payload sections have been used or are in development. The vehicle has been operated in configurations ranging from simply the bow and tail section to the full four section length. Joining rings allow the vehicle to be opened either by lifting fairing sections out while keeping the vehicle intact, or by separating vehicle sections. Core vehicle systems are rated to 4500 m, although the buoy section is limited to 1500 m.

Vehicle Description

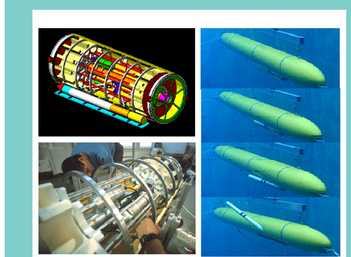


The science payload consists of two components: water column sensors for tracking water masses, and an upward-looking sonar (ULS) for ice draft characterization. The water column measurements include conductivity, temperature, depth, nitrate, oxygen, and optical backscatter intensity. Twin pumped SeaBird CTD systems are mounted near the nose of the vehicle, with Sea Bird dissolved oxygen and ISUS Nitrate sensors inline with one pumped system. The goal of the ice sonar is to field an instrument that provides SCICEX equivalent ice draft data.



The ice-penetrating capability of the buoy was field-tested initially using a full-scale buoy at the APLIS ice camp operated by the Office of Naval Research in April 1999. Tests of deployment, ice penetration, and antennae deployment were carried out using a buoy in early 2001 at Lake Winniepesauki (shown here).

Three in-vehicle navigation systems were evaluated in the Arctic. The first, a Ring Laser Gyroscope(RLG) Inertial Navigation System (INS), aided by a 300 kHz RDI Workhorse Navigator Doppler Velocity Log (DVL), is shown in the rightmost figure above. This system, developed by Kearfott Guidance and Navigation Corporation, utilizes a set of three orthogonal optical gyroscopes, each based on a 24 cm long, triangular light path. This INS is capable of unaided drifts on the order of 800m/hour, aided drifts of .5m/hour, and heading accuracy of >.01 degrees. The second navigation system, an OCTANS optical gyrocompass manufactured by IXSEA, is located at the rear of the vehicle section and shown in the middle figure above. This system utilizes an orthogonal triad of fiber optic gyroscopes (FOGs) and accelerometers to determine the direction of true north. The Octans can determine heading to .2 degrees∗secant of latitude, or 1.43 degrees at our operational latitudes of 82 degrees north. A major limitation of FOG technology is temperature sensitivity of the glass fibers; Ixsea has developed innovative techniques for handling this problem. The third in-vehicle system, a DMU-AHRS flux gate magnetic compass from Crossbow, is located in the vehicle tail section. This system consists of a orthogonal triad of flux gate magnetometers, accelerometers, and piezo-electric gyroscopes. The compass computes magnetic heading based on magnetic field, pitch, and roll measurements, and stabilizes this relatively noisy measurement of north using gyroscope measurements of rotational rate. A fourth system, a FOG-based Inertial Navigation System from Grumman, arrived late and was only tested on shipboard.

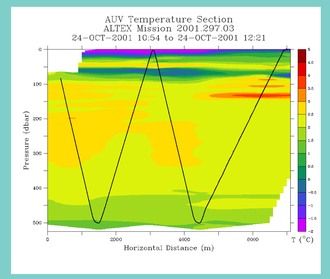


Communication from the vehicle to shore is provided by a battery of 12 expendable buoys, launched from the vehicle, capable of melting through the ice and transmitting stored data files via Argos. When the Pyrosolve-Z is expended, a balloon containing GPS and Argos antennae is inflated. After the antenna deployment, the buoy obtains a GPS fix and initiates its data telemetry via Argos. Because there is no communication between the vehicle and the buoys, this information is not available to the vehicle. During summer 2001, integration tests of the buoy launcher and buoys were conducted at MBARI. These tests successfully demonstrated the ability of the AUV to download data while underway, and the buoys safely eject while the vehicle maintained straight and level flight.

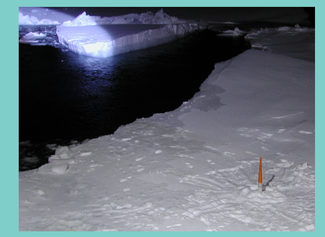
The tailcone has successfully been tested and tuned to handle the short vehicle configuration (no fuel cell or buoy section), the intermediate vehicle length (this length includes the fuel cell), and the full length vehicle.

Cruise Results

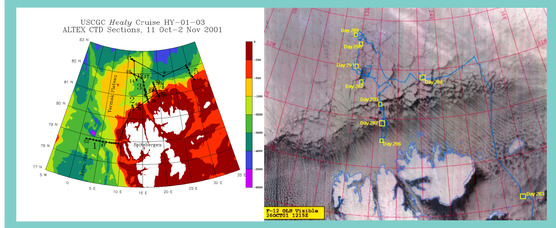
The cruise departed Tromso, Norway on October 7th and returned on November 4th. From an operational perspective, timing of the cruise was not ideal for AUV operations in the Arctic. Diminishing light and temperatures imposed severe restrictions on operations as the cruise progressed. However, by organizing activities to ensure that those which required light and moderate temperatures were satisfied early, we were able to use the ship time highly productively.



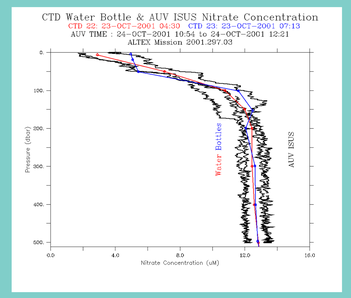
This temperature section along an undulating AUV track shows horizontal variability. The salinity variations compensated such that the water density profile was statically stable. This 7km test mission to 500 m lasted 87 minutes.



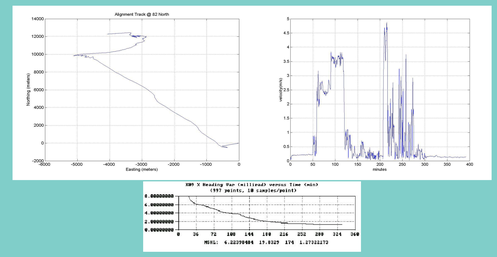
During the cruise, buoys were assembled shipboard since they could not be shipped intact. Under-ice tests of the buoys confirmed the ability to download data and sequence through the deployment and extension operation. Unfortunately, melt-through was not achieved owing to contaminated Pyrosolve-Z compound. Even without demonstrating complete melt-through, the buoys were able to successfully deploy their antennas and acquire GPS fixes. Two buoys were left behind in ice floes to autonomously transmit data to ARGOS for multiple days.



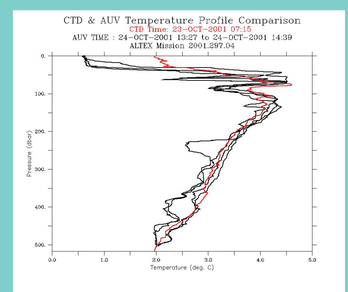
Cruise tracks. (a) Fifty-two shipboard CTD casts formed five sections that tracked the warm Atlantic layer inflow from Fram Strait to 30 deg E. The CTD casts also provided an accuracy check on the AUV measurements. (b) Forty-six AUV missions were performed, featuring over four hours of under-ice operations as well as a 22km transect crossing the Atlantic inflow. No AUV operations occurred after day 296 due to high winds, cold and darkness.



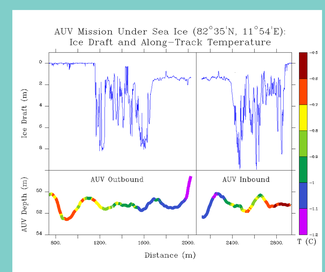
The AUV carried an in-situ ultraviolet spectrophotometer (ISUS, developed at MBARI) that measured the nitrate concentration while underway. The ISUS measurements agree well with water-bottle nutrient samples that were frozen for later laboratory analysis. The ISUS observations are 5 second averaged (~2-3 m vertically averaged) and reduced by 2.4 uM to match the water bottle measurements at 500 dbar.



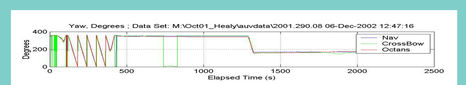
A key figure of merit for Inertial Navigation Systems is their ability to compute initial heading, pitch, and roll. Typically, INS's use a combination of gyro compassing, or measurement of the horizontal components of the Earth's rotation, and propagation of GPS-measured velocities and positions, to determine their initial orientation. At high latitudes, this alignment can incur large errors due to relatively small horizontal Earth rate terms; pre-cruise simulations had shown this error could be as large as 4.0 mRad. The three plots above detail a 350 minute alignment of the Kearfott Ring Laser Gyroscope (RLG) INS at 82 degrees north. The ship maneuvering consisted of both slow drifts in the ice, as well as straight line motions at up to 9 knots. The resulting alignment had an error of 1.95 mRad, based on GPS measurements, which was equivalent to the errors encountered at mid latitudes. The plot below shows comparative heading data from the magnetic and gyroscopic references at 11.8 degrees east, the highest magnetic inclination encountered. The ring laser gyro and magnetic heading systems correlated with a .89 correlation coefficient.

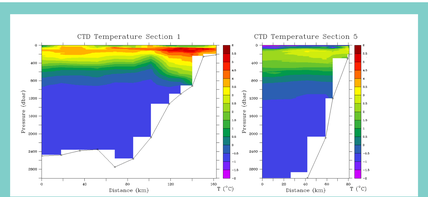


The CTD and AUV each carried dual, pumped, temperature and conductivity sensors for cross-validation. Though 30 hours apart, the CTD profile and the four AUV yo-yoing profiles show reasonable agreement within the temporal and horizontal variability.



An AUV mission out and back under sea ice. The ice-profiling sonar on the AUV, cruising nearly level at 50 m, measured an ice thickness of up to 10 m. Similar ice structures can be identified outbound and inbound. At constant depth, the water temperature decreased as the AUV traveled from open water, beneath the ice keels and under the flat, 2 m thick ice beyond.





(a) CTD Section 1 in Fram Strait showing the warm Atlantic Layer water core in the upper right at 5-6 deg. C, flowing into the Arctic Ocean. (b) CTD Section 5 northeast of Spitsbergen showing that the warm Atlantic Layer core has cooled to 3.0-3.5 deg. C, but is still identifiable.

Acknowledgements

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Promoting Partnerships for the Future of Oceanography

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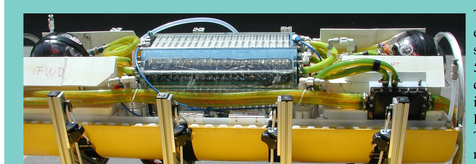
Future Work



To achieve the desired range capability, we have been developing a fuel cell energy system constructed by Fuel Cell Technologies, Ltd. The fuel cell vehicle section utilizes the high energy density of aluminum, and the oxygen content of 50% peroxide to produce a depth independent renewable energy source. The complete system for 66 kWh of net energy packaged as a neutrally buoyant section is designed to fit in a 1.9 meter long by 0.51 meter diameter (21 inch) hull section. For this vehicle, the 66 kWh net allows a 1400 km range at 3 Knots for 260 hours. The system being developed is pressure compensated and therefore deep-ocean rated. Depth independence is achieved through storage of only solid or liquid reactants and wastes. Energy density for the fuel cell alone based on current tests of full size cells is projected to be over 310 (Wh/kg dry weight).