An Energy Conserving Oceanographic Profiler For Use Under Mobile Ice Cover; ICYCLER

George A. Fowler, Greg R. Siddall and Simon J.Prinsenberg

Bedford Institute of Oceanography, Department of Fisheries & Oceans,

Dartmouth, Nova Scotia, Canada

ABSTRACT

ICYCLER is a moored oceanographic profiler designed to measure surface layer water properties under mobile ice cover. The profiler can provide daily 50 meter salinity-temperature-chlorophyll profiles for a full year. Data are collected during each profiling ascent with an instrumented float that avoids ice impact using an onboard echo sounder. Once measurements are acquired, the sensors are hauled back down to an ice-free depth. An efficient energy-conserving mechanical design minimizes power requirements to allow for a logistically manageable and hydrodynamically efficient package. An ICYCLER prototype was successfully used the Canadian Arctic Archipelago for a year-long deployment and a second re-designed ICYCLER is being tested for Arctic deployment in the summer of 2004.

KEY WORDS: Icycler; Profiler; Mooring; Energy-conserving; Ice.

INTRODUCTION

Scientists suspect that our polar ice caps are melting and that the additional freshwater being introduced could affect ocean processes and possibly change global ocean circulation. To address this, oceanographers need to measure the seasonal variability of freshwater flux from the Arctic Ocean through the Canadian Arctic Archipelago. The only way to do this, using current sensor technology, is to sample the water insitu near the surface, since this is where the freshwater is concentrated. The problem for oceanographers is that the surface of the Arctic Ocean is frequently covered with ice.

Suspending an instrument through the ice is often not practical because the ice is unstable for long periods of the year. To approach surface water from below has the advantage of making measurements at a fixed location, but Arctic ice is not of even thickness and is often mobile. This makes navigating an instrument through these waters hazardous and imposes special requirements to ensure data recovery. To address this problem, the Bedford Institute of Oceanography (BIO) has developed a new instrument called "*Icycler*".

MOORING DESCRIPTION

Ice thickness can vary drastically where ice sheets have jammed together from the effects of strong currents or high winds. As these ice ridges sweep down channel, instruments down to a depth of 30 meters or more are at risk. In deeper water, it's not necessary to initiate profiles from the seafloor because traditional moorings can be used below the ice hazard zone.

Two-Float Assembly

Icycler uses a two-float assembly to create a midwater platform from which profiling is initiated (Fig. 1). This reduces energy consumption by enabling a much smaller float to lift the sensors the rest of the way towards the surface.

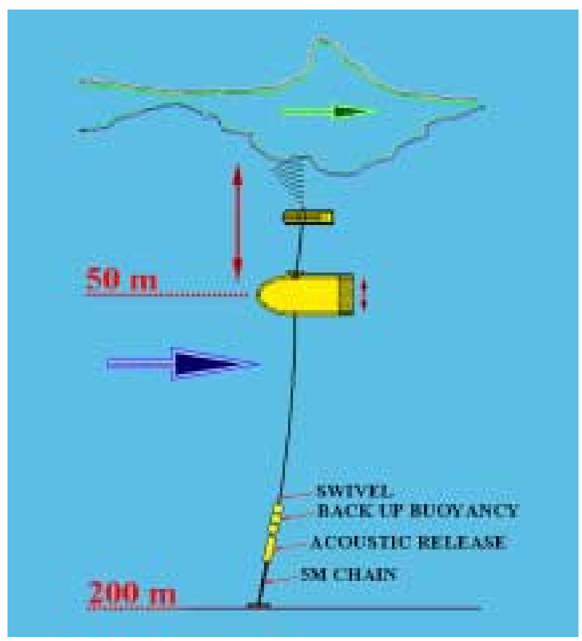

Fig. 1, Typical Icycler mooring configuration showing two-float assembly.

The Sensor Float

Icycler's sensor float (Fig. 2) uses a streamlined OpenSeas "SUB" enclosure (Hamilton, Fowler, Belliveau, 1997) to contain a Seabird 19+ CTD with pump and a Wetlabs fluorometer to collect data, while a Datasonics echo sounder monitors the distance to the underside of the ice during each profile. The pump draws water from outside the enclosure through an anti-foulant device located at the entry point.

Sensor data are relayed to electronics located on the midwater platform via electro-mechanical cable. The electronics provide data storage, and controls the height to which sensors are profiled.

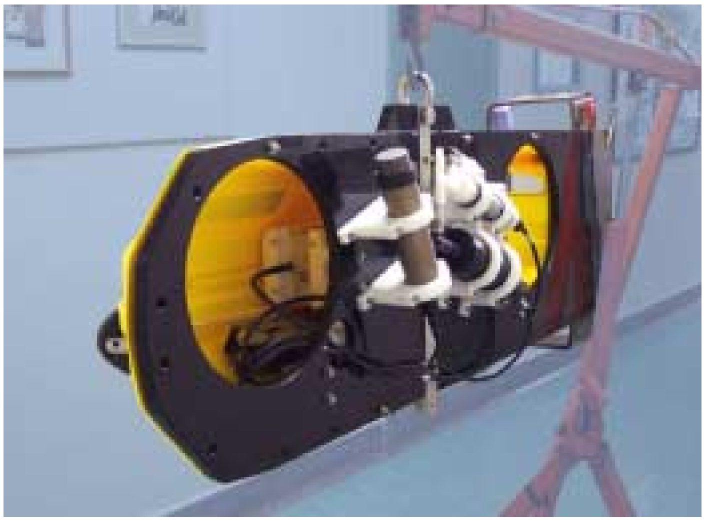

Fig. 2, Sensor float with fairing and buoyancy spheres removed.

Energy-Balancing Mechanical Design

To further reduce energy requirements, Icycler mechanically stores the energy gained from the ascent portion of a profile, and then uses this stored energy to power the descent phase. The only energy consumed during the profiling cycle, is what's lost to mechanical inefficiencies and imbalanced float drag.

The instrument is packaged into a two-float assembly, with the lower float containing ten times as much buoyancy as the upper float. The larger "midwater float" contains a winch assembly with two drums, and the smaller "sensor float" contains the oceanographic sensors and echo sounder. The winch operates both drums simultaneously, and is configured to pull the midwater float down through the water column as the sensor float rises towards the surface. On the next phase of the cycle, the sensor float is winched down while the midwater float is allowed to float back up to its original depth. By varying the ratios of float buoyancies and depths traversed, most of the profiling energy can be conserved. This is illustrated more precisely by equating the change of potential energies between the two floats as they cycle,

$$Bs \times Ds = (Bm+Bs) \times Dm \quad (1)$$

where Bs and Bm are respective net buoyancies, and Ds and Dm are distances traveled by the sensor and midwater floats.

Or stated another way; a small buoyancy traveling a large distance can represent the same energy as a large buoyancy traveling a short distance (Fowler, 2002).

Icycler uses this energy-conserving principal to reduce battery weight, and thereby gain buoyancy without increasing platform size. This approach is proving to be an efficient method of maintaining performance in higher water flow conditions and improves the ability to deploy the instrument from ships of opportunity.

The maximum distance traveled by the sensor float (Ds) was chosen to be 66 meters. The desired net buoyancy of the sensor float (Bs) was determined using BIO's mooring model and an acceptable vertical excursion error for known water velocity profiles. A value of 134 N (or 30 lbs) was chosen for Bs. The distance traveled by the midwater float was chosen to be approximately 10% of Ds or 6 meters. Substituting these values into the energy balance equation (Eq.1), determines a buoyancy value of 1200 N (or 270 lbs) for the midwater float, and results in a maximum net profiling capability of 60 meters at zero water current.

Performance In High Water Currents

When operating in high water currents, the instrument's maximum profiling height is reduced because hydrodynamic drag causes the mooring to bend over. Icycler's hydrodynamic performance is modeled in Figure 3.

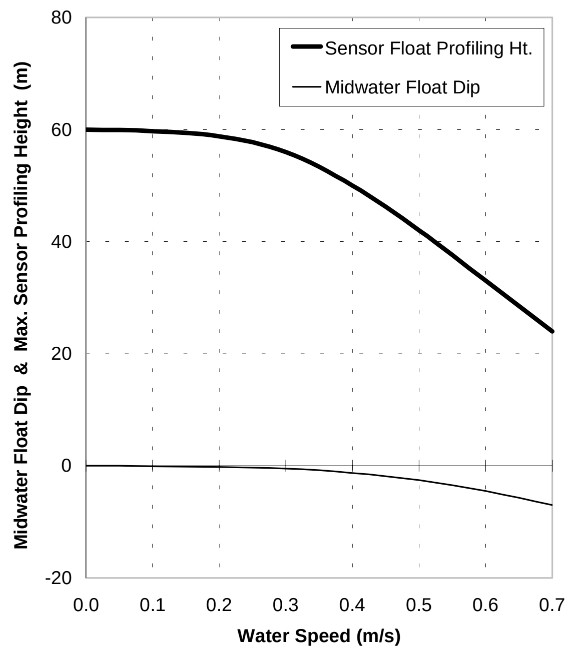

Fig. 3, Icycler's maximum profiling height and midwater float dip vs. water speed in 200 meters of water.

It predicts that 40-meter profiles are possible in 0.5 meter/second water currents when the device is moored in 200 meters of water. This combination of operating parameters meets the requirement for the Canadian Arctic Archipelago experiment now underway.

The Icycler design attempts to minimize the mooring dip problem by using streamlined and hydrodynamically stable fairings, but the real secret to its success lies in its energy-conserving design. Releasing more cable to achieve greater profiling heights works well when currents are light, but as water speeds increase, the mooring's catenary shape requires increasingly more cable length to reach ever-diminishing profile heights. Adding more buoyancy to the system limits the down-stream excursion of the mooring, but it also substantially increases the size and weight of the device, because more energy is required to profile the additional buoyancy. Increasing the energy requirement offsets the advantage of increased buoyancy, because additional battery weight is required to provide autonomous operation.

Cable Spooling

Efficient cable spooling is required to maintain constant drum diameter, maximize cable lengths and prolong the life of the electro-mechanical cable. Icycler uses stationary fairleads and a translating winch to achieve this. The winch drums travel together on four linear bearings, and a static leadscrew engages one of the rotating drums to traverse the winch. The winch is made neutrally buoyant so that it has no effect on float trim as it spools. The profiling cables use kevlar strength members to reduce weight for the same reason.

To maintain the energy balance, the instrument needs to pay out ten times as much cable to the sensors, as it retracts from the anchor. This is achieved using different drum diameters with gear reduction applied between them. The cables are wrapped onto their drums using only a single layer to avoid changing the effective drum diameter causing energy imbalance.

THE ICYCLER PROTOTYPE

The Bedford Institute of Oceanography has developed a working prototype that has spent a year in Lancaster Sound in the Canadian Arctic Archipelago. While it successfully completed 350 cycles over the year-long deployment, a programming error limited the height of each of the profiles. The program was corrected, and the device was re-deployed in the same location for another year with recovery scheduled for summer of 2004. The year-long data record from the 2002/03 deployment is shown in Figure 4.

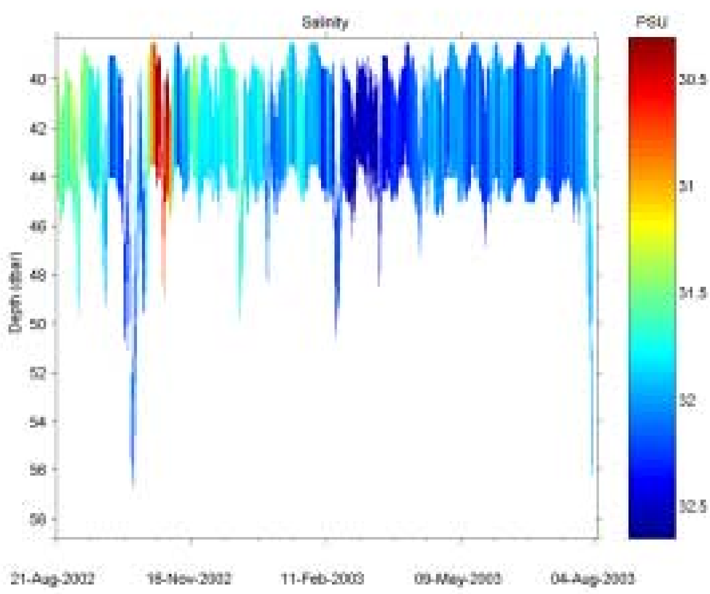

Fig. 4, Year-long salinity record collected by Icycler prototype in Lancaster Sound from August 2002 to August 2003.

It shows that fresher surface water (Salinity 30.4) is being mixed down to 50 meters in late summer and becomes saltier during the winter months possibly due to salt rejection from the growing pack ice. The biweekly variation in profiling height and range is probably caused by tidal action when monitoring sea level height at the same time each day.

Problems Encountered With Prototype

The extensive work accomplished with the prototype has pointed out several shortcomings in the original design. Energy losses were traced to a motor shaft seal, and the linear bearings employed to permit lateral travel of the winch drums suffered from exposure to seawater. A reverse locking clutch caused problems when ice cover was not present because storm induced motion in the water column forced the clutch into an overrunning mode. The chain-drive system, while very efficient underwater, was subject to stretch that caused problems with the reversing drive.

THE SECOND-GENERATION ICYCLER

Using the experience gained from the prototype, a new Icycler, (Figs. 5 & 6), has been completed and is being tested in the Gulf of St. Lawrence. It's anticipated that it will replace the Icycler currently moored in Lancaster Sound in August 2004 as part of the Canadian Archipelago Through-Flow Study (CATS).

Fig. 5. Second-generation Icycler.

The new Icycler embodies several innovations to make it more efficient. The motor shaft seal and reverse locking clutch have been eliminated completely by using a unique counterbalanced motor mounting. The chain drive has been replaced with efficient underwater gearing, and the winch assembly is now hung from linear roller bearings that will enable smoother operation. These new developments should permit the system to operate more efficiently and achieve its objectives within the scientific program.

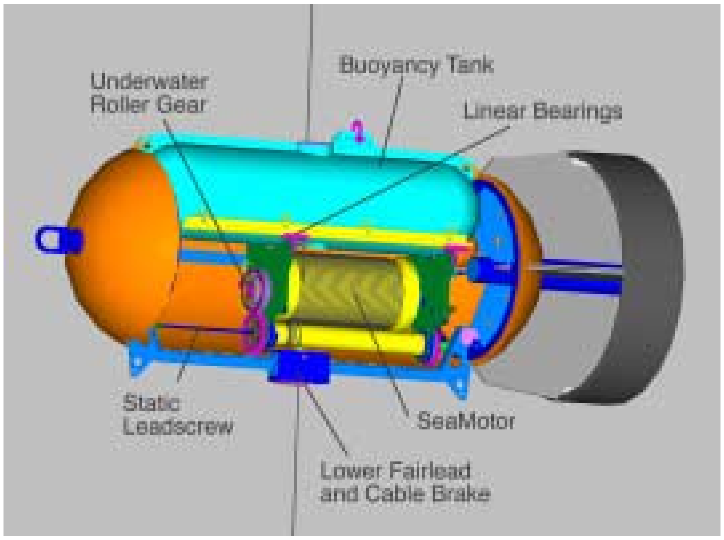

Fig. 6, Rendering of new Icycler with fairing partially removed.

New Drive System called *"SeaMotor"*

A new self-contained drive mechanism, called *"SeaMotor"*, (Fig. 7), was developed to simplify power transmission and enhance reliability. SeaMotor's watertight exterior case functions as one of the profiling winch drums. This saves space and eliminates the need for underwater slip-rings since the drum always rotates with the cable stored on it.


Fig. 7, SeaMotor with winch drum/pressure case removed.

SeaMotor powers the winch without the use of rotating seals. This is highly desirable because sealing a rotating shaft against hydrostatic pressure causes friction creating energy loss. The friction also makes the seal susceptible to wear, which can cause pressure cases to leak. SeaMotor eliminates rotating seals by packaging the drivemotor and battery together on a pendulum inside the pressure case. The pendulum is suspended below bearings supported at the centre of both endcaps and the drivemotor engages a gear on the winch drum.

Winch drum torque is created by pushing against gravity, rather than an external frame. This is analogous to a mouse on an exercise wheel. As the mouse attempts to climb up the inside of the wheel, the mouse's own weight creates a torque on the wheel causing it to rotate. On SeaMotor, the drivemotor pushes against the weight of the suspended battery to rotate the drum.

Electronics Configuration

The electronics are mounted inside SeaMotor, on the pendulum, using internal (dry) slip rings to connect the oceanographic sensors (Fig. 7). This positions all of the electrical devices (excluding sensors) in one location to reduce the number of underwater connectors, and to simplify wiring.

A efficient brushless drivemotor provides good motor control and increases durability. Tilt sensors monitor pendulum position and thus torque exerted by the motor. A pair of hall-effect sensors are used to measure cable payout and direction. The hall-effect sensors are mounted on the electronics board and detect small magnets spaced around the inside of the drum.

Cable payout is re-calibrated before each profiling cycle using a proximity switch to dock the winch carriage at one end of the float. When the winch achieves this 'home' position, the sensor float is assumed to be fully retracted allowing the software to re-initialize cable position. Cable lengths are arranged to provide a few meters of separation between the two floats at this time.

Efficient Underwater Gearing

Sprockets were selected to transmit power between the SeaMotor and second winch drum because of their high underwater efficiency. Belts and spur gears do not work well in this environment because energy is lost squeezing water between contact points. Sprockets minimize viscous loses by engaging rollers that are spaced apart. Efficiency is maintained by the spacing, since it provides a generous exit path for water to escape through.

Instead of using flexible chain to connect the sprockets, plastic rollers were mounted on an idler-gear. The rollers are sized and spaced apart around the circumference of the gear to match sprocket pitch. This arrangement maintains underwater sprocket efficiency while eliminating slack chain and stretch; two factors that often cause problems with reversing chain drives.

Cable Management During Deployment

The instrument is deployed using conventional techniques, except that a drogue is attached to the anchor to slow it's decent. This limits instrument overshoot when the anchor hits the bottom to reduce snap-loading on the device.

A ratchet lock helps to dissipate residual anchor cable loads experienced during deployment. A pawl engages the anchor cable winch drum until the instrument initiates its first profiling cycle. At this time, an over-center spring disengages the lock for the remainder of the deployment.

Two hydrostatically released cable brakes maintain precise spooling of the cables during deployment. Until the instrument is completely submerged underwater, it's possible for cable tensions to go slack allowing stored cable to unwind off the winch drums and tangle. The brakes prevent this until hydrostatic pressure releases them at depth.

Buoyancy & Frame Design

Midwater float buoyancy is provided by a welded stainless steel pressure vessel using spherical endcaps and internal bulkheads to save weight. The tank also serves as the structural backbone for the entire float. Several trawl floats are used to adjust float trim.

An axial frame design was used to secure the fairings, and to position handling lugs at the bow and stern. The lugs also serve to support the instrument on its storage stand, (Fig. 8). This arrangement allows the entire midwater float to rotate about it's longitudinal axis for ease of assembly, and to provide vertical access for loading the 50kg SeaMotor via over-head crane.

The streamlined fairings are made from molded fiberglass, and are designed to avoid flat surfaces which cause hydrodynamic instability. A cylindrical tail aligns the float into the direction of water flow.

Fig. 8, New Icycler on storage stand with "SeaMotor" in foreground.

SAMPLE DATA

The Icycler prototype was deployed under ice in the Gulf of St. Lawrence during the winter of 2001. Data from this deployment (Fig. 9) is presented to show the high quality of measurements that can be obtained using the device.

(NOTE: The authors hope to replace the data shown in Figure 9 with new data anticipated from winter 2004 deployments using the second-generation version of the instrument. If new data are not available in time, we will explain the data gaps.)

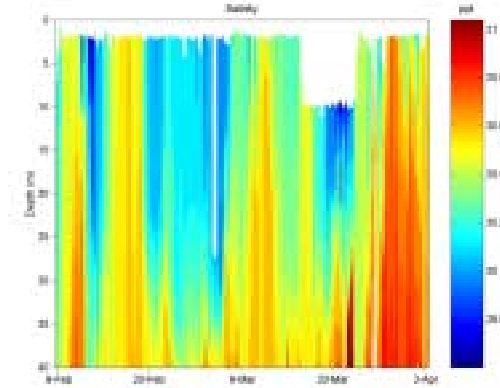

Fig. 9, Salinity data from Icycler prototype deployed under ice in the Gulf of St. Lawrence during the winter of 2001.

OTHER APPLICATIONS

There is interest in applying Icycler technology to other applications such as wave-zone avoidance or to enable satellite communication, but the ultimate goal would be to extend Icycler's profiling height beyond 60 meters. A marginal increase in profiling height could be achieved by simply extending the length of the current design, or by making other changes such as using thinner cable between the two floats.

To increase profiling height significantly, requires a substantial increase in buoyancy to balance the extra profiling distance and limit mooring dip. This is also complicated by the need to replace the current spooling gear with a design that would store multiple layers of cable to save space. These options are currently being explored.

CONCLUSIONS

Icycler's unique energy conserving features enable surface layer water properties to be measured under mobile ice cover using a logistically manageable and hydrodynamically efficient package. This has been demonstrated by the prototype and from modelling work. A second-generation version of the instrument is expected to increase the efficiency of the system and enhance reliability.

ACKNOWLEDGEMENTS

The authors would like to thank Icycler's development team at the Bedford Institute of Oceanography for the fabrication of prototypes and Brian Beanlands for software development, Murry Scotney for mooring and logistic support, and Jim Hamilton for modeling assistance. Internal and external reviewers are thanked for their helpful comments on the various drafts of the manuscript. Personnel of Canadian Coast Guard icebreakers are thanked for their continued support during field operations. This work was supported by the Canadian Panel on Energy Research and Development, and the Department of Fisheries and Ocean's Strategic Science Fund.

REFERENCES

Fowler, GA, (2002) "A Moored Energy Conserving Oceanographic Profiler," *Proceedings of the Int. Oceanology 2002 Exhibition and Conference, London, UK, March 5-8, 2002*, 11 pg.

Hamilton, JM, Fowler, GA, and Belliveau, DJ (1997). "Mooring Vibration as a Source of Current Meter Error and its Correction," *J.Atmos. and Oceanic Tech*., Vol 14, No3, pp. 644-655.