SeaCycler: A moored open-ocean profiling system for the upper ocean in extended self-contained deployments

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Abstract

The upper ocean, including the biologically productive euphotic zone and the mixed layer, has great relevance for studies of physical, biogeochemical, and ecosystem processes and their interaction. Observing this layer with a continuous presence, sampling many of the relevant variables, and with sufficient vertical resolution, has remained a challenge. Here a system is presented which can be deployed on the top of deep-ocean moorings, at depths of 150-200m, and which mechanically winches a large sensor float to the surface and back down again, typically twice per day for periods up to 1 year. The sensor float can carry several sizeable sensors and has enough buoyancy to reach the surface even in the presence of strong currents. The system can survive mooring blow-over to 1000m depth. The battery-operated design is made possible by using a balanced energy-conserving principle. Robustness is enhanced with a drive assembly that employs a single rotating part that has no slip rings or rotating seals. The profiling bodies can break the surface and establish satellite communication for data relay or reception of new commands. An inductive pass-through mode allows communication with other mooring components throughout the water column beneath the system. A number of successful demonstration deployments have been completed.

Introduction

The upper layer of the ocean, from the surface to approximately 100-150m depth, is a very dynamic component of the oceanic water column. It contains important physical, biogeochemical, and biological processes, which need to be observed intensively in order to unravel their interconnection or even just to gain information about the short-term variability, climate-driven responses, or long-term evolutions in this layer. For a wide variety of quantities it is necessary to know the vertical structure (gradients or maximum/minimum layers) and/or the vertical integral or the vertical movement of layers. Prominent examples are phytoplankton (which usually have a subsurface maximum), nutrients, or pCO_2 (whose vertical distribution is needed for carbon budgets and fluxes). For these reasons, time series collected with fixed point sensors often deliver insufficient information. Some variables can now be observed with small and power-efficient sensors, such that they can be mounted on underwater gliders or profiling floats, in order to obtain vertical profile information. Other variables require larger or more power-hungry sensors, e.g. imaging flow-through systems like LOPCs (Laser Optical Plankton Counter) and wet chemical sensors for carbon variables or nutrients. Also, time series may be needed in locations where gliders cannot hold station well enough (strong current systems or in eddy fields). This requires a profiling technology which can be mounted on moorings, in order to transport sensors through the surface layer.

Moorings with a surface buoy are difficult to use for profiling systems, since the mooring wire moves violently under the action of surface waves. The current preferred approach therefore is to use a subsurface mooring which ends approximately 150m below the surface, and attach a winch-like system there. This approach is also less subject to extreme weather conditions, since it can stay below the surface when waves and wind are too severe, and is less likely to be damaged by ships or vandalism. More importantly, a winched system avoids the “reef effect”, i.e. marine life that gathers around surface moorings, and thus can observe a more undisturbed marine ecosystem. Also, parking a sensor system at 150m significantly reduces biofouling issues.

There are a number of challenges, however, with a moored underwater winched system which need to be overcome. A main factor is the energy efficiency, assuming the entire mooring is self-contained and thus battery-operated. Plain winching requires significant energy to pull down a body which has enough buoyancy to overcome the blow-over due to horizontal drag in typical surface ocean currents. This drag is especially serious when large and heavy sensors are to be deployed on the profiling body. A second challenge is the operation of rotating mechanical parts and electric motors underwater over long durations. Typically this requires rotating seals and underwater electrical slip rings, which increase the risk of failure when deployed for time periods in the order of one year. A third complication is the fact that subsurface moorings in the deep ocean (5000m depth) may be blown over by strong current events such as eddies. At high latitudes these currents can be deep-reaching, and may cause the components which are normally at 150m depth to be pushed down to depths of 700-1000m. Thus the entire winch assembly needs to be pressure resistant to such depths. Finally, in order to establish communication to shore it is necessary to break the surface and remain there while transmitting data or receiving commands. This is hazardous and challenging because a large float with ample buoyancy will be subject to snap loading in the wave field, while a small float may be continually swamped by waves or may not even reach the surface in the presence of currents.

This paper presents an approach which tries to address and solve all the challenges resulting from the above requirements. The engineering team was guided by the science team over the course of 6 years and many designs were developed, jointly considered, and iterated, until the system now called SeaCycler emerged. Several ideas and principles are derived from an earlier system called ICYCLER which was developed for an entirely different application. The solution and implementation presented here combines the following features:

- an energy-conserving principle, to increase power efficiency by an order of magnitude over conventional systems (Fowler, 2004)
- an internally-enclosed drive system (no rotating seals or slip-rings) to increase reliability
- a large instrument payload (60kg in air) permitting flexible scientific studies

- a “Sensor Float” buoyancy of 110kg to allow surfacing in strong currents
- a pressure rating of 1000m, to allow deployment on deep open-ocean moorings
- extra cable storage (total of 373m net) to compensate for blow-over in currents
- a “parking depth” of 150m, to avoid reef effect, vandalism, and reduce bio-fouling
- ambient wave sensing capability to avoid surfacing when conditions are too severe
- a separate “Communication Float” to establish shore telemetry even when too rough for surfacing the Sensor Float
- remote re-tasking
- simple straight-through cable routing, anchor to surface, allowing inductive modem coupling to deeper-water instrumentation
- an endurance of approximately two or four 150m profiles per day in a year-long deployment, for alkaline or lithium batteries, respectively
- 540kg buoyancy to help maintain a taut mooring
- an ability to surface the Sensor Float for maintenance without recovering the mooring.

This system has been deployed for engineering and demonstration purposes multiple times now, and during the most recent deployment carried out 644 round-trip profiles from 150m depth using an alkaline battery pack.

Background and Parallel Work

The concept of the oceanographic profiler has been, and continues to be, fertile ground for developers. Approaches vary, driven by specific scientific applications, the particular concept employed by the developer and advances in available equipment and expertise like those we have seen in the field of battery technology. The one constant has been the general recognition that it is almost impossible for one piece of equipment to do everything. The result has been the creation of several different innovative systems.

One of the earliest examples is the Cyclesonde which operates in the upper 200m and is driven by variable buoyancy on a wire mooring (Van Leer et al, 1973) and this has evolved to deeper water and a much greater number of profiles on a subsurface mooring (Erikson et al, 1982). This drive method continues to be actively pursued as witness more recent work by Provost and du Chauffaut (1996) and Waldmann (1999). The concept of running on a taut wire has been dramatically extended by Doherty et al. (1999). Here, a neutrally buoyant body, using a traction motor carries a varied sensor suite over vast distances on a subsurface mooring. This technology has been commercialized in the hopes of making it more accessible to the oceanographic community (Morrison, 2000). An alternate taut wire profiler works from the top down using wave energy for drive power generated by the motion of a surface buoy (Fowler et al, 1997).

A different class of profilers is based on various winch configurations. A mid-water mounted system designed to examine the fresh water layer under mobile ice cover has operated for a year under Arctic ice (Fowler et al., 2004). An innovative profiler that carries the winching component on-board the profiling element from the bottom, or mid-water support, to the surface, incorporating various methods of data communication and control has been developed (Barnard et al., 2010). Finally, an arrangement (Budéus, 2009) that combines a system of weight transfer to travel to great depth on a taut wire with a winched system built by NGK near the top of the mooring to carry a buoyant element to the surface has been described.

Technical Implementation

Mechanical design

As shown in Figure 1, the SeaCycler system is comprised of three floats connected by electro-mechanical cable. At the top is a Communication Float (short "Comm Float", 5kg net buoyancy), followed by a Sensor Float (105kg net buoyancy including an extensive sensor suite). Both floats travel in tandem through the water column under the control of the lower Mechanism Float (435kg buoyancy) which also provides floatation for the mooring that connects it to the ocean bottom. The Mechanism Float contains a winch drum/motor assembly, shown in the detail in figure 1, which is not only highly efficient but also mechanically simple. The smaller diameter section of the drum stores 6mm diameter 3x19 steel galvanized plastic jacketed mooring wire (1800kg breaking strength) and the larger diameter section carries a near-neutrally buoyant plastic jacketed, Spectra strength member, 3 conductor, profiling cable leading to the Sensor Float. Rotation of the double drum produces differential movement of the two cables in the ratio of the drum diameters, here set at 5:1. Since the cables are wound in opposite directions, drum rotation causes the profiling floats and the Mechanism Float to move vertically in opposite directions. Because the various buoyancies are carefully designed to produce tensions in the cables which are in the inverse ratio of 1:5, the drum is in static balance and can therefore be rotated with very little torque and resultant power. Put another way, rotation of the drum changes the potential energy of the Sensor and Comm Floats and this is offset by an equal and opposite change in potential energy of the Mechanism Float. This energy-conserving principle has been patented.

Several challenges were met in the design and the integration of the winch drum's drive motor assembly. Primary among these was the need to overcome the projected cyclical unbalancing torques caused by wave forcing when profiling elements approach the surface. These forces, in combination with the large torque arm offered by the drum, forced a new approach to underwater motor design. Instead of mounting the drive motor on the centerline, where immense output torque would be required, it was connected near the outside diameter of the drum to a large internal gear. To resist anticipated high ambient pressures, this assembly was housed in a torus shaped pressure case (1.1m outer diameter). This geometry offers substantial diameter to create torque while keeping the wall thickness of the pressure case relatively thin to generate a lightweight assembly. The drive mechanism inside the torus consists of the large internal gear integral with a substantial steel ring that is supported on five bearings mounted on the torus enclosure wall. These bearings disconnect the ring, and gear, rotationally, from the torus. The ring is eccentrically weighted to create a pendulum. A very small DC motor mounted on the torus is engaged with the internal gear on the ring so that when the motor rotates it causes the torus, with attached winch drum, to rotate around the centerline of the pendulum ring. Since the batteries and control electronics are also located inside the drum (see below) and thus rotate with the entire assembly including the small DC motor, no slip rings are required to transmit the power. A separate publication is underway which will present the engineering and implementation details of this novel torus drive system.

Significantly, gravity, working on the pendulum ring, acts as an elastic vertical reference, or “foot on the ground” from which to create torque. When the torus rotates under no-load conditions the pendulum ring remains comparatively stationary but under load, the pendulum rotates to create torque so that the whole assembly is rotationally compliant; an absolutely critical feature for a structure that operates in the wave zone. Notably, all the gearing and relative motion required to produce drum rotation occurs in air, within the torus itself, enhancing efficiency. Because all the components rotate around the totally enclosed pendulum ring, the need for rotary seals is eliminated. The system provides seamless connectivity between the motor, control and monitoring electronics and battery packs mounted within the drum and between the cables extending above and below the mechanism.

At low profiling speeds the major part of the energy required to move the Sensor and Comm Floats in the water column is produced by the frictional forces within the mechanism itself. To reduce frictional losses, the neutrally buoyant drum translates horizontally under fixed location fairleads while cable, laid in a single wrap, is pulled in or paid out. This eliminates the need for power consuming and mechanically complex spooling mechanisms. Since friction reduction is so critical for power conservation, great care was taken with the design of all rotating elements. All fairleads and the main winch shaft are supported on ball bearings which are enclosed in specially designed, pressure compensated housings that isolate them from seawater and have proven to be highly efficient. Drum translation is supported on simple low friction bushings based on the fact that almost all system power is devoted to rotation while virtually no power is required for translation at very low speeds.

At first glance the winch drum may seem ungainly but its large size actually serves multiple purposes. The larger section is 1.15m in diameter and 1m long capable of storing 466m of profiling cable in a single wrap. It is also large enough to house the electronics and all the batteries (576 alkaline D-cells in four packs) needed to power drum rotation. Although the mechanism is in static balance due to the buoyancies and cable wrapping, external forces such as the hydrodynamic wave loading on the profiling floats as they approach the surface can impose significant torsional forces on the drum. These forces are resisted by the above motor assembly with the torus-shaped pressure housing having almost the same major diameter as the larger section of the drum itself. The motor is thus capable of substantial output torque. Finally, sufficient space is available to include enough syntactic foam to render the whole drum assembly neutrally buoyant which is essential to maintain level trim as the drum translates. The motor assembly, winch batteries and control electronics all rotate with the drum providing a seamless cable routing right through the entire SeaCycler assembly from the ocean floor to its surface. The importance of this is discussed in more detail in following sections.

Power budgets

It is essential that adequate float buoyancy be provided to ensure that oceanographic sensors and communication elements reach the surface when high water currents are encountered. Further, both the ascent and descent must be accomplished under controlled conditions to ensure proper instrument function. For the operational parameters defined in this project where the parking depth is set at 150m, and with a substantial sensor suite that can add to float size, models predict, and we have found, that a profiling buoyancy of 110kg is required for optimal performance. Actual field experience indicates that the SeaCycler operates with an overall power consumption of 61 watts and this includes power for mechanism control and monitoring electronics. Comparisons with a “conventional” winch system, where the profiling buoyancy must be pulled down by brute force, but is allowed to “free ascend” under control to the surface are difficult because of assumptions that must be made about efficiencies and low load power requirements. Nonetheless, calculations show that the SeaCycler should be in the order of 10-12 times more efficient. For equal on-board power that means 10-12 times more profiles.

The Mechanism Float carries 600 ampere-hours at 24 volts of energy in alkaline batteries for profiling and to power the electronics. In the current configuration, power is adequate to complete 650, 150m round-trip profiles or 195 km vertical travel. The Sensor Float carries a 14 volt, 320 ampere hour Lithium battery pack that powers the main system control electronics, all the sensors (at present – CTD and Dissolved Oxygen) plus the Comm Float electronics and transceivers. Replacing the Mechanism Float batteries with lithium cells would permit more than doubling the number of profiles, or alternatively complete up to 2 profiles per day for a year in areas that experience much higher water currents that will need more cable payout to reach the surface. To do this would also require doubling the Sensor Float power since instruments will be on for longer periods of time. There is sufficient space and reserve buoyancy on the float to accommodate this change as well as increase sensor payload to eight instruments. New Sensor Float electronics are being developed which will allow even more sensors to be integrated. Plans also call for a Comm Float re-design which would, among other things, enable it to be powered independently.

Electronic interfacing, communication

Main functional control, instrument management, winch control, data storage and communication reside on the Sensor Float, with multi-conductor electro-mechanical cable providing connectivity between the three floats. Ancillary data storage is also sited on both the Mechanism and Comm Floats. Inter-component communication is accomplished through a direct, full duplex serial link using 3 conductors on the electro-mechanical interface cables.

The Sensor Float manages the mission planning for the SeaCycler system. This includes parameters such as the profiling interval, profiling speed, the number and frequency of instrument equilibration stops, file transferring, surfacing aggressiveness, etc. All of these parameters can be modified by the shore operator during any of the regular telemetry sessions. Provisions have been made for the Sensor Float to “wake up” and/or reset any of the SeaCycler sub-systems as required. The profiling sequence is governed entirely by Sensor Float commands, which can be dispersed to all instruments and sub-systems. In addition, an acoustic modem is included on the Sensor Float to provide an operator with rudimentary control and status during periods where the Comm Float is submerged. Currently it is configured to act solely as a “Full System Reset Mechanism” to bring the Sensor Float to the surface in the case of a catastrophic electronic communication failure. In the future, though, it will also be used for auxiliary instrument data transfer, system control and status reporting.

The Mechanism Float contains its own, somewhat autonomous control system which responds to both simple and complex commands from the Sensor Float. Simple commands include functions such as turning the brake on or off, while more complicated commands can effect a complete surfacing profile based solely on the Mechanism Float’s internally established criteria. The Mechanism Float electronics incorporates sensors which allow it to control and monitor all of its internal functions. Operating parameters, such as winch drum speed, maximum allowable torque and motor current are accessed locally, but can be overridden by commands directly from the Sensor Float, or from the shore operator via the Comm Float to the Sensor Float.

Two-way communication over the Internet between a shore computer and the SeaCycler is typically accomplished via an Iridium transceiver located on the Comm Float which also includes a GPS engine. Local communication with the surfaced Comm Float, i.e. to a ship in the vicinity, can also be accomplished via a FreeWave transceiver which automatically disables Iridium communication for that particular telemetry session. The Comm Float is a completely, self contained communications sub-system. All of the Iridium, FreeWave and GPS communications are controlled by the Comm Float electronics. Files destined for shore are typically transferred from the Sensor Float to the Comm Float during the surfacing phase of the profile, where they are stored in the Comm Float’s internal file system. A command from the Sensor Float then relinquishes control to the Comm Float where it will establish the connection, transfer files and receive new commands from shore. All new files are automatically transferred to shore but any of the archived files may be re-transmitted at the request of the shore operator. Time updates from the GPS and commands from the shore operator are transferred to the Sensor Float to be later dispersed throughout the system.

The uninterrupted nature of the cable routing from the Comm Float though the Sensor Float through the Mechanism Float winch drum to the mooring line below means that direct communication is possible from shore to the ocean bottom. Currently, communication with instrumentation located on the mooring line beneath the Mechanism Float has been accomplished using an inductive modem.

Iridium/GPS emergency recovery beacons are located on both the Sensor Float and the Mechanism Float. With the planned stand-alone power on the Comm Float an emergency recovery beacon can be implemented there as well.

Performance aspects

There are four separate functional features that affect the ability of a system to approach the surface, pierce it to send and receive data, and then submerge. The first is the need for extra profiling cable beyond the absolute depth of the system. As noted above, SeaCycler carries, and can deploy, a net 372m of profiling cable to reach the surface.

The second is the effect that varying wave forces have on any structure or body at or near the surface. These forces can have a very negative effect on the longevity of systems that are “unyielding” and have the potential of imposing exaggerated snap-loads on fixed cable structures. The design of the

SeaCycler motor, however, has built-in and automatic compliance that radically reduces potential stress on the system and can, under certain circumstances even "give up" cable if forces become excessive.

The third aspect, piercing the surface, is accomplished by SeaCycler's Comm Float. This relatively small component, about 1.5m long, floats near vertical when submerged at the top of a 23m long double armored steel cable that is rendered neutrally buoyant by the addition of discrete syntactic foam buoyancy elements. When it pierces the surface it flips to an almost level attitude because of off-centre ballasting. In this state it projects a three element antenna above the surface, see figure 2. The combination of neutrally buoyant cable lead-in, ballast placement and the very large water-plane area created by its near-horizontal attitude dramatically enhances stability, allowing the Comm Float to transmit and receive messages in significant waves of many different wavelengths and periods.

The fourth function, submerging in heavy weather, however, constitutes a significant challenge. In early trials it was found that when the weather got rough, in seas of over 4 m, the Comm Float could sometimes be left on the surface for extended periods after an Iridium communication session. This was caused by excessive wave drag force on the profiling elements exceeding maximum motor torque so that they could not be hauled down. This was eventually overcome with a stratagem that took advantage of SeaCyler's unique motor/energy balance principle. As noted, the three buoyancies that comprise the assembly are organized to maintain balance. When this balance is upset, for instance when transient wave forces are encountered, the system attempts to restore this balance automatically and autonomously in a very useful way. In the normal stopped position, for example when on the surface and transmitting, the system is locked with an internal brake. It was found, however, that if the brake was disengaged, the system's predisposition to maintain balance took over and the profiling elements were “jacked down” by passing waves as the Mechanism float, momentarily out of balance with applied cable tensions, rose in the water column to take up slack. This technique has become standard procedure and the system has been programmed to remove the brake for two minutes after each surface session. Even in relatively calm, 1m seas, the profiling elements are often hauled down to a depth of 10m. But as wave height increases, the “down-jacking” becomes more intense so that, instead of expending considerable energy to submerge, the waves provide a “free-ride” down to 20m or more in larger waves. This is particularly advantageous in helping the SeaCycler escape from rough sea conditions where wave loading might cause disastrously high cable tensions. The more severe the threat is from waves, the deeper the waves drive the profiling floats down away from the challenging wave environment.

It should be noted that surfacing the Sensor Float on command allows it to be recovered, e.g. to service/replace sensors, while keeping the remaining mooring including the Mechanism Float in place and operational. Figure 3 shows the Comm and Sensor Floats on the surface for a mid-deployment buoyancy adjustment using a small boat.

Demonstration

Between March 2010 and May 2011, seven deployments have been accomplished; three in local waters, two in ~150m water depth 32 km off Halifax, and two at the edge of the Scotian shelf in ~1100m depth 250 km offshore. These field tests were combined with countless laboratory and jetty tests. The five inshore and near-shore test deployments were of short duration, typically 3 days, with the offshore deployments lasting 74 and 41 days respectively. As would be expected for a development this ambitious, early deployments identified minor shortcomings. These were corrected with additional innovations or additions to culminate in the last deployment which was highly successful both from a performance perspective but also from the standpoint of operational development. Chief among these was the implementation and refinement of the autonomous wave driven submergence. Over the duration of the last deployment the power savings realized through this technique represented 26, 150m round-trip profiles, or 4% of the 644 profiles completed, expending no rotational power at all. Of all the profiles attempted, only one failed to reach the surface and the Comm Float was never left on the surface for more time than intended. Figure 4 shows all three float bodies on the research vessel prior to deployment.

A major part of the testing process was concerned with the evaluation of communication capability. Initial satellite communication difficulties were identified as a possible compatibility issue with the TCP/IP stack in Windows XP and the shore-side server software. After migrating to Windows 7 (which has a more current TCP/IP stack design), the problem disappeared. Further investigation is ongoing with Microsoft and Iridium to fully understand the matter, but for now it is not viewed as a serious issue. This malfunction resulted in many early dropped calls but all of the data were recovered during shore-requested re-transmission. The system's operating characteristics were frequently varied from shore.

Normal Sensor Float "stop depth" was set at 5m, but on 82 occasions it was brought to within 1m of the surface and on 23 profiles the CTD was surfaced into air. Indeed, on command, the top end of the Sensor float was actually brought above the surface. These surfacings and near-surfacings were only attempted in benign conditions. On the other end of the spectrum, successful two-way communication was demonstrated in wave heights over 4m. The instrumentation carried on all the deployments worked flawlessly with 100% data recovery rate. Instrument data is shown in Figure 5 for the 644 profiles of the most recent deployment.

Power consumption was found to be very close to original estimates with an average winch power rate of 60.7 watts while profiling or 1.53 KW-Hr per 150m round trip, when additional power demands of surfacing and submerging are included. The total number of profiles completed is commensurate with original design objective. Although project planning called for only 365 profiles, supplementary battery power was provided to deploy and recover an additional amount of cable to surface the profiling floats in higher water currents. In the event, water currents at the site proved to be very low with only 2m to 4m of additional cable required to reach the surface, so the extra energy was used to complete 644x150m roundtrip profiles instead.

Outlook and Future Applications

At the time of writing, SeaCyler is being prepared for a test deployment under the NSF funded OOI project. For this it will carry a pCO_2 sensor and an acoustic current meter in addition to the CTD and Dissolved Oxygen sensor. The plan is to migrate the technology from the BIO Ocean Physics group to the commercial manufacturer/vendor, Rolls-Royce Canada Limited - Naval Marine. We feel confident that the SeaCycler principle provides a very robust and energy-efficient method of obtaining profiling data in the upper ocean. Sensors that lend themselves to integration range from CTD and current meters, fluorometers and backscatter sensors, and incoming radiation sensors, to acoustic zooplankton sonars, wet chemical systems for carbon and nutrient measurements, and LOPC systems. It is possible to move to steel wire for all cables, providing more fishbite resistance. In this case additional electronic cable communication complexity will be necessary to permit operation using a single conductor rather than the multi-conductor system currently employed. The additional weight of the wire spooled out can be compensated by tapered drums to keep the system balanced. Experience needs to be gathered with procedures and possibly hardware for safe deployment and recovery of the large and heavy SeaCycler system. Recovery may be simplified by first detaching SeaCycler from the subsurface mooring with an acoustic release – this will be explored during the OOI test deployment.

An additional modification for future applications may be possible by providing power to the mechanism float from below (in case a seafloor cable is available to provide power). Also, this version of SeaCycler is the most ambitious design, allowing for blow-over to 1000m depth. It may be possible to build modified versions for coastal applications that only need to operate to depths of 200m.

Overall, SeaCycler is an underwater moored winch system that is designed for applications in demanding situations, which is highly flexible and robust, and has proven its readiness for extended field deployments in research applications.

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Figures

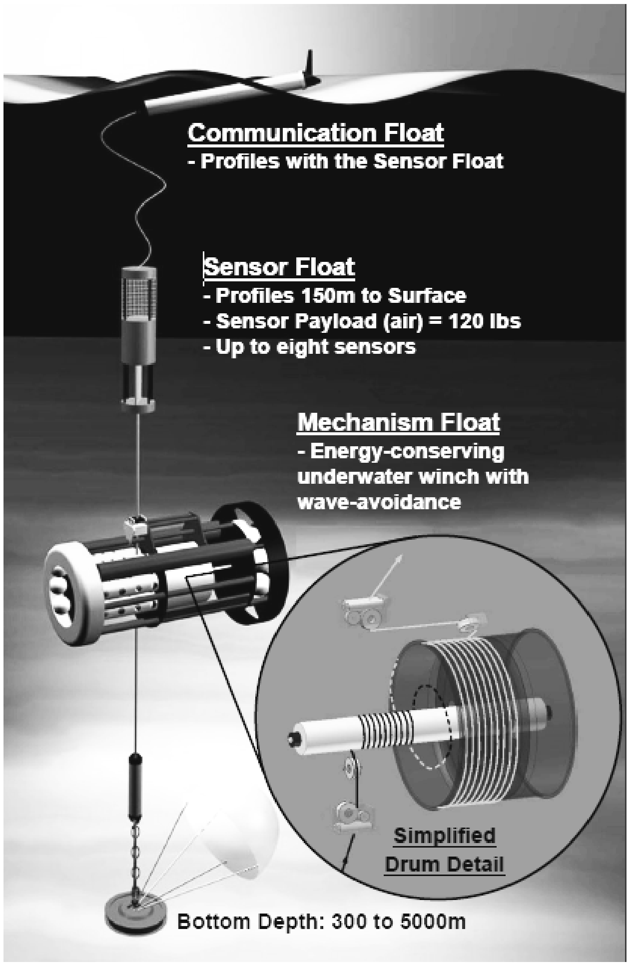

Figure 1:
Schematic showing the overall design and configuration of the SeaCycler system. The Mechanism Float (MF) is typically parked at 165m depth with the Sensor Float (SF) pulled in close. The Communication Float (CF) is connected via 23m of fixed-length cable. During profiling, the MF moves downward while the SF ascends, in a 5:1 ratio. If there are no water currents and associated blow-over of either the mooring with the MF and/or of the SF, the MF winches itself down to 195m while the SF reaches the surface. To allow for mooring blow-over, the total cable stored allows for spooling out 466m of cable for the SF, and this requires 93m cable capacity for the MF. At maximum pay-out the MF may thus be at a depth of 258m, resulting in a “net” SF cable length (relative to 150m) of 373m, or 223m of spare profiling capacity allowing for mooring blow-over. Dimension of the floats are: MF length 4.0m, max diameter 1.8m, air weight 1850kg, buoyancy 440kg; SF length 2.5m, max diameter 0.6m, air weight 230kg, buoyancy 105kg, Communication Float length 1.4m, max diameter 0.1m, air weight 18kg, buoyancy 0.2kg.

Figure 2:
Communication Float in its operating position at the surface. Tank and field studies have shown remarkable stability of this waves ranging from capillary, to wind waves and swell, always keeping the antennas out of the water.

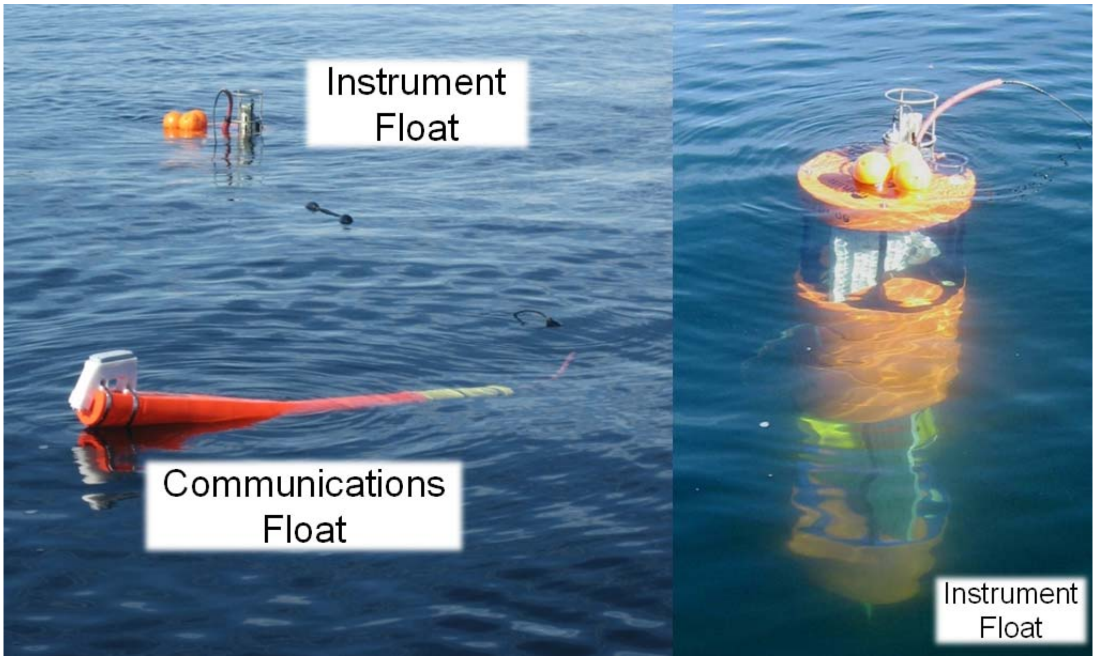

Figure 3:
Photographs showing the Comm and Sensor Floats on the surface during mid-deployment. The CTD sensor is out of the water, the remainder of the Sensor Float remained submerged. Commanding the winch to spool out all available cable gives 223m of cable for pulling out the floats for service or swapping, while keeping the mooring in place.

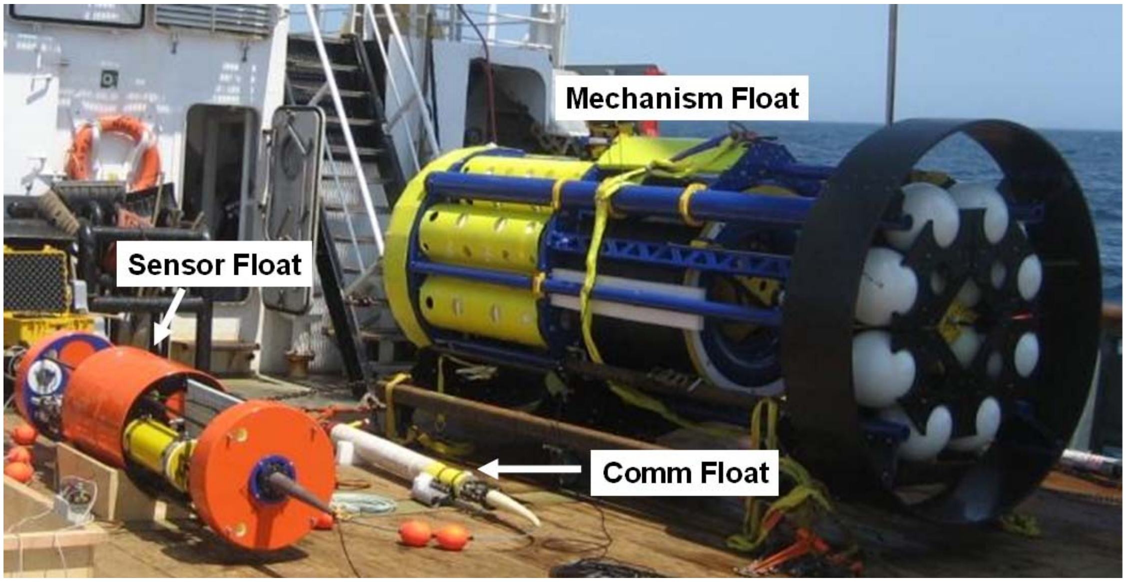

Figure 4:
View of all three float bodies on a research vessel prior to deployment. The Sensor Float is seen to have ample spare capacity for additional sensors, batteries, or electronics.

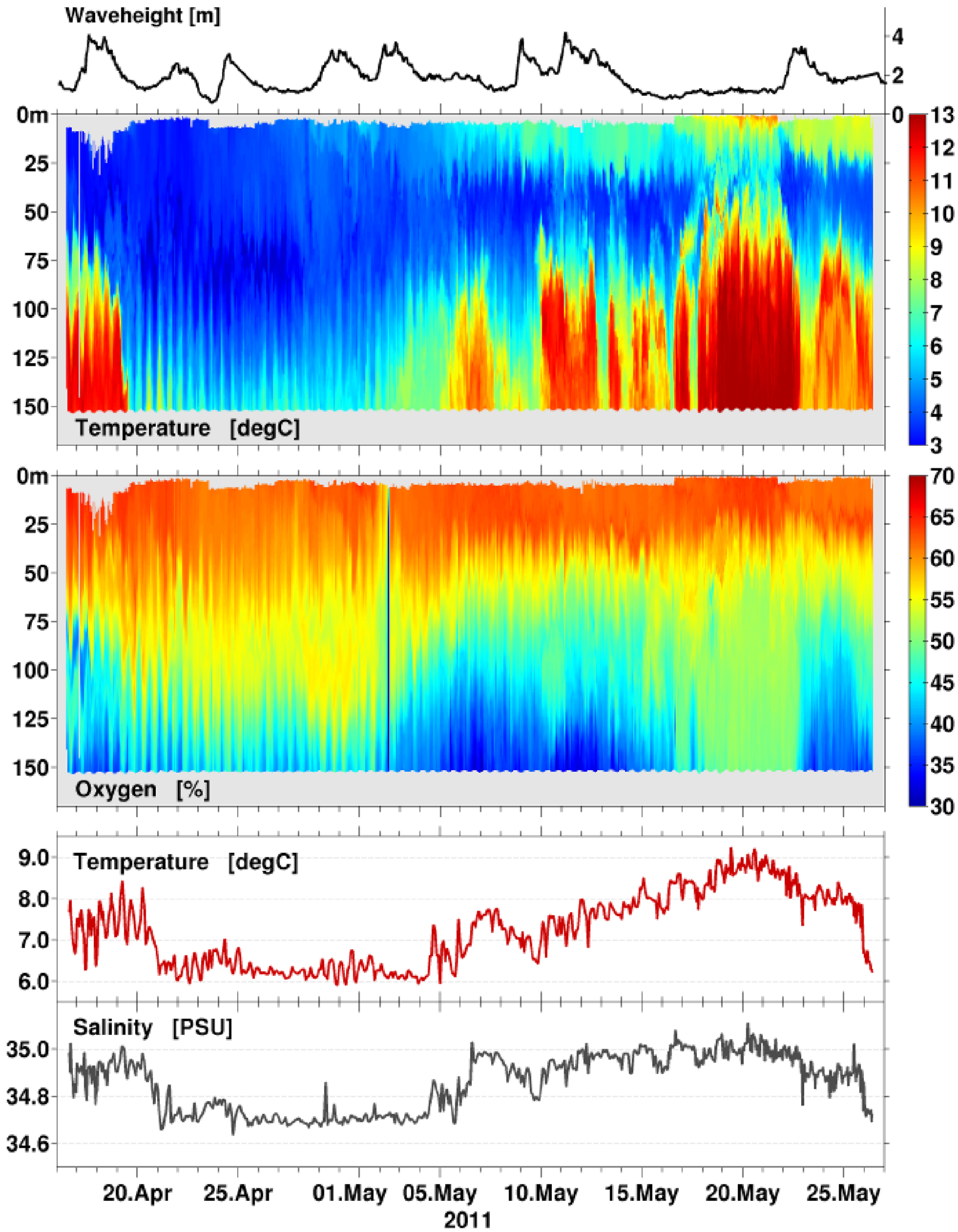

Figure 5:
Timeseries display of the real-time recovered data via the Comm Float for all 644 profiles from the last deployment in 1100m water depth in the open ocean off Halifax (April-May 2011), together with wave conditions from a near-by NDBC buoy. Data collected all the way to the surface is seen in benign wave conditions. The lowest two panels show data that were retrieved from a microcat further down in the mooring, using the inductive communication capability resulting from the single connected cable routining from the Comm Float to the mooring wire below SeaCycler.