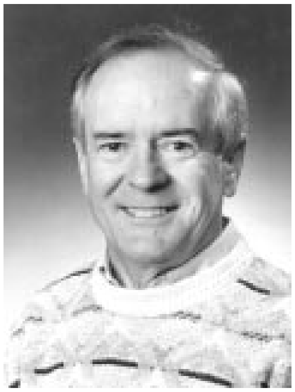
Upper Ocean Profiling from Vessels While Underway

J.-G. Dessureault and R.A. Clarke



J.-G. Dessureault

R.A. Clarke

Background

For more than a century, sub-surface information has been collected using oceanographic vessels. These vessels steam somewhat slower than a commuter on a bicycle, and when they also occupy oceanographic stations their average speed is reduced to that of a pedestrian. It is little wonder that oceanographers can be said to have never conducted a program in which they have oversampled the phenomena being studied.

Oceanographers have recognized the limitations of their vessels and tools for a number of years. In 1937, Spilhaus developed the bathythermograph which could provide a temperature profile to 275 m. Naval vessels are said to have taken bathythermograph casts at speeds exceeding 25 knots, but probably at some risk. In the late 50's and early 60's, engineers began to design and build electronic instrumentation for oceanographic observations. Instruments to measure the upper ocean temperature field were among the first to be useful. Three different classes of instruments were developed.

The towed thermistor chain consisted of a large number of thermistors spaced along a cable towed astern of a vessel at speeds of a few knots. The bottom of the cable was held at some fixed depth by a weight or depressor and the instrument provided Temperature (T) versus time (distance) data at a number of fixed depths. These temperature chains were used to study internal waves in the upper 100 m but soon fell out of use. Because each thermistor was connected to a separate conductor leading back to the ship and the recording equipment, these systems were difficult to maintain and calibrate. However, they provided the high horizontal spatial resolution needed for investigations of internal wave phenomena.

The Bedford Institute of Oceanography (BIO) developed one of the first towed profiling bodies to be marketed, BATFISH (Dessureault, 1976). This is capable of profiling the upper 400 m of the water column at speeds up to 10 knots. This body was first equipped with a Conductivity, Temperature, Depth (CTD) package but the sensor suite has expanded over the years to include fluorometer, particle counter, light meter and dissolved oxygen meter. These bodies are towed using hard faired cables to minimize cable drag; this requires large specialized winches and sheave blocks and restricts their use to research vessels. The slope of the profiles are generally less than one to four; hence these systems can observe horizontal scales down to a few kilometres and are most useful in studies of fronts, jets and eddies as well as biological patchiness and interactions between the physical environment, phytoplanktons and zooplanktons.

Finally there are the expendable probes which can be deployed from both ships and aircrafts. Probes are now available to measure temperature, temperature and conductivity, sound speed and velocity profiles to depths of 1500 m. Millions of Expendable BathyThermograph (XBT) profiles have provided the basis for what we know about the global climatology of the heat content of the upper ocean. XBT's deployed from merchant vessels remain one of the principal tools available to designers of ocean

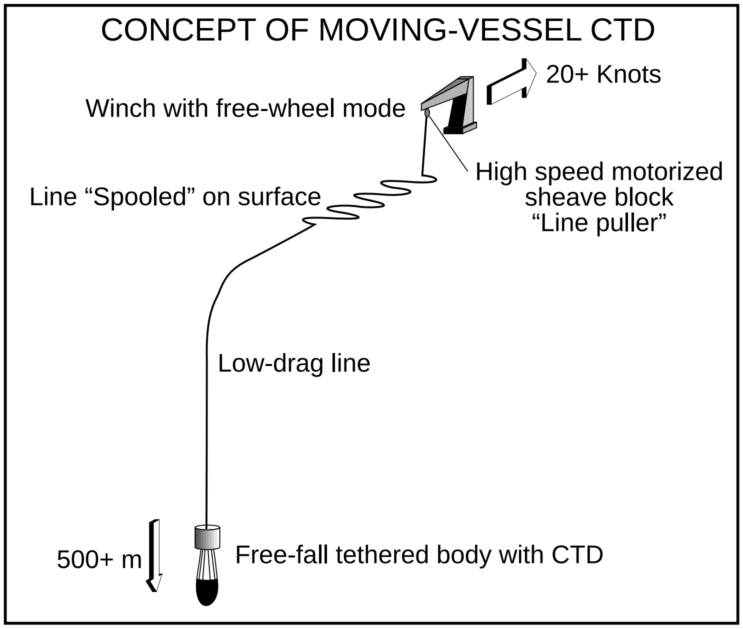


Figure 1: Concept of the Moving Vessel CTD system.

climate observing programs such as Tropical Ocean Global Atmosphere (TOGA), World Ocean Circulation Experiment (WOCE) and their successor Climate Variability and Predictability (CLIVAR).

Temperature data alone are not always sufficient to describe variability in the upper and intermediate layers of the ocean. Density is a function of both temperature and salinity. Changes in the fresh water budget in the northern parts of the North Atlantic are thought to modulate the strength of late winter convection and hence the vertical circulation of the Atlantic and even of the global ocean. The delays in the development of accurate, affordable and reliable eXpendable CTD (XCTD) probes frustrated WOCE and TOGA planners who had written such probes into their planning documents.

Development at BIO

The development at BIO of an underway profiling system was prompted by the desire to provide an alternative to XCTD technology. Conceptually, this new system is like a bathythermograph (Fig. 1). The differences are that the body is heavier and tear-drop shaped, the mechanical sensing and recording elements are replaced by a modern small, robust and self contained CTD unit and the line is paid out fast enough to be loose on the water. It is being called Moving Vessel CTD (MV-CTD).

The bathythermograph was restricted to depths of 275 m or less. We wished to develop a system that could obtain profiles to depths of up to 1500 m or deeper and that could be deployed from vessels with cruising speeds up to 22-25 knots. The system is being designed for unattended operation on merchant vessels. It will be a computer controlled system where the deployment and recovery of the probe will be initiated by a single command issued by the officer-of-the-watch on the bridge.

The present prototype system consists of a tethered free-fall underwater body with a drogue, a CTD, a tether line, a line puller, a docking chute, a winch and a computer with control software.

The underwater body (Fig. 2) is a tear-drop shaped brass casting with a stabilizing tail shroud. It is one metre long, weighs 80 kg and is suspended by a bridle pivoted slightly behind its centre of gravity. The bridle is designed so that the body both descends and ascends through the water column nose first. The body towed in this fashion is very stable; even as it approaches the vessel through the turbulence of the propellers. The stabilizing tail shroud serves the additional function of protecting the CTD sensors on recovery of the body. In order to stop the fish from swinging into the stern of the vessel as it is lifted out of water, a drogue line is attached to the bridle. On the prototype system, the drogue line is deployed and recovered by hand. During underway operations, it is hoped that the ship's master will consent to leaving the drogue line in the water between casts. The drogue would be deployed by the crew on reaching the open sea and recovered at the end of the voyage as the vessel approaches its final destination.

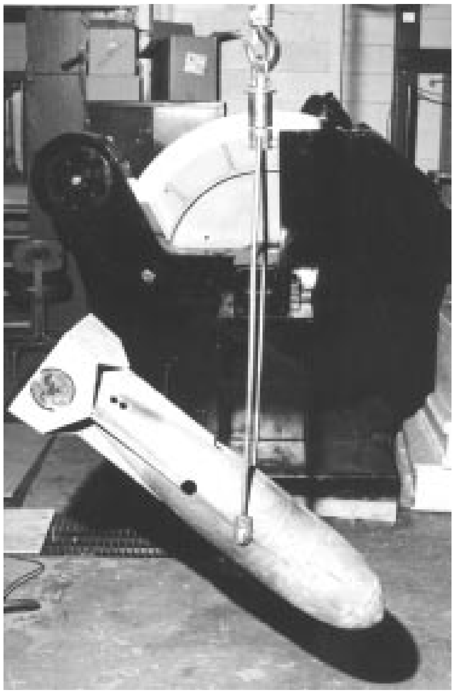


Figure 2: The underwater body and the winch in the background.

A Falmouth Scientific, Inc. Micro-CTD was selected as the sensor package because of its size, accuracy and robustness. Its inductive conductivity sensor should be more stable than a four electrode sensor in an operational environment in which the sensor is neither cleaned nor kept filled with distilled water between profiles. The CTD is controlled by a Tattletale-8 computer that, together with a battery pack and radio modem, is contained in a separate pressure case within the underwater unit. The Tattletale computer communicates with a computer on board the vessel through a radio modem when the fish is in its cradle. At the beginning of a cast, the Tattletale turns on the CTD for an eight minute period and receives and stores the CTD data. On recovery, and in response to a command via the radio modem, the Tattletale downloads the data to the shipboard computer and then goes into a sleep mode. The Tattletale computer's sleep mode allows the battery pack to supply sufficient power for nearly one thousand profiles over periods of weeks. This means that the pressure case does not need to be opened to replace the batteries during a normal field expedition.

The line puller "pulls" the line from the free-wheeling drum at a controlled speed and feeds it onto the water. It consists of two 30-cm diameter pinch rollers, one of which is hydraulically powered. The line puller is mounted on an axis which runs athwart ship, thus it is able to pivot so that the plane of the unit remains parallel to the line as it leads aft of the vessel during recovery. The line puller needs to be capable of paying out line at high speed. Deployments from a 22 knot vessel require pay-out rates of more than 17 m s-1.

Because the line is "pushed" onto the turbulent water by the high speed line puller, it must be supple so that it does not kink easily. The highest tension in the line arise when the recovery operation begins. The momentum of the body and of the line have to be absorbed and then the recovery winch speed added to the vessel speed produce a tangential drag on the line which can easily reach its working strength. Therefore, the line needs to have a high strength versus diameter ratio and a low tangential drag coefficient. The low tangential drag minimizes the slowing of the descent speed of the body and reduces the tension during recovery.

The tangential drag on a cable is much less than its transverse drag, hence, a streamline body with a high terminal velocity will tend to pull its cable along the surface of the ocean and then vertically behind it as it falls. The water acts as a

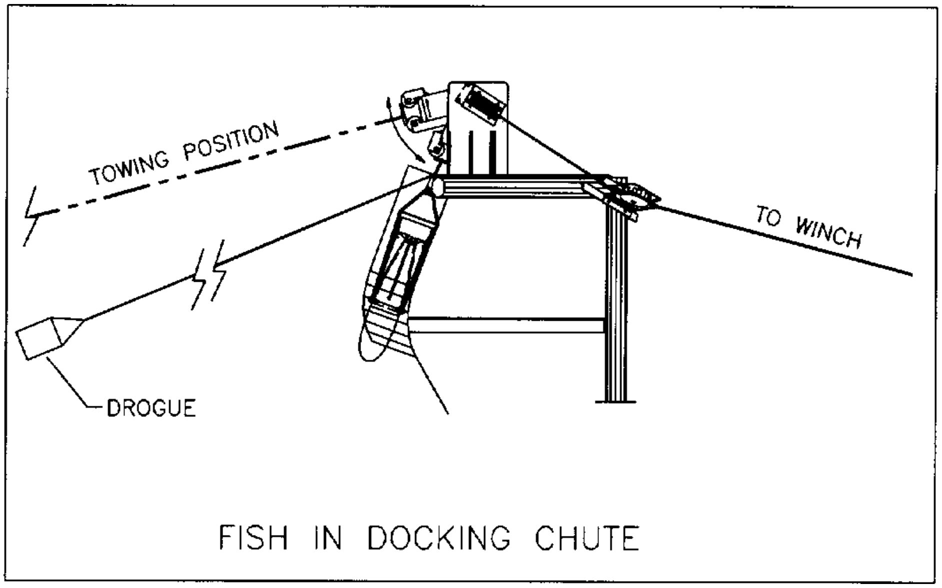


Figure 3: Side view of the davit, line puller and docking chute.

virtual sheave at the point of entry in the water of the body. This process is helped if the winch and cable handling system is able to pay the cable onto the sea surface at a speed greater or equal to the sum of the ship's speed plus the fish's drop rate. The same phenomena means that when the system stops paying out and starts winching in the cable, the fish will rise vertically towards the sea surface with a vertical velocity that is nearly equal to the ship's speed plus the winch's speed. Hence such a system will provide both down and up profiles close to the location at which the probe was released.

Early in the design of this system, we decided not to use electromechanical cable because we were concerned about its reliability in unattended operations. We saw three possible areas of concern. First was the area where the cable enters the fish since the fish needs to rotate at least 180 degrees about its pivot point. Second was the reliability of the electrical conductors in a cable that was being deployed under no tension and then suddenly recovered at its full working load. Third was the potential requirement for an electromechanical swivel at the fish. In the series of tests to date, we have used 8-mm diameter braided aramid fibre cable with a rated breaking strength of 36 kN. For higher speed operations and a greater safety margin, we will change to a larger (11 mm) diameter line and eventually will require a smooth urethane jacket which has a lower tangential drag coefficient.

An electromechanical cable is necessary in operations which require the data in real time. Brooke Ocean Technology Ltd. is currently designing a modified system using electromechanical cable to obtain sound velocity profiles for use with multi-beam sounding systems. This system is being designed for use to a depth of 100 m at a speed of 10 knots.

The davit and docking chute (Fig. 3) was an integrated unit that had been designed to simplify installation on various vessels. The davit is attached to the vessel through a single base plate with some braces to the rail. Attached to the davit are two sheaves which route the cable from the winch to the line puller mounted directly above the docking chute. These sheaves allow the winch to be placed in a variety of different positions relative to the docking chute and hence permit the system to be adapted to different vessel layouts. The chute is a metal cradle whose curved and flared outboard end extends beyond and below the top of the ship's after bulwark. Between profiles, the underwater body lays in the chute without the necessity of lashing or clamping.

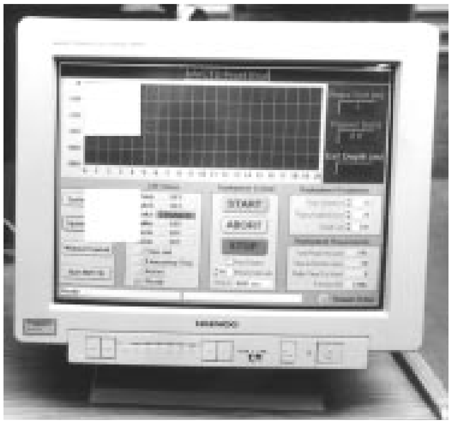


Figure 4: Control computer screen.

The winch drum diameter is large (1 m) to reduce the number of layers of cable, hence reducing the crushing pressure and simplifying the spooling. The winch can hold 3000 m of line and can recover the fish at 1.4 m s-1 with a pull of 14 kN. The present winch is driven by an electric motor; the next model will be driven by an hydraulic motor, sharing the hydraulic power unit with the line puller. This modification will permit faster recovery speeds. Presently the fish reaches 600 m in 160 s; the recovery of the line and fish then takes 15 min.

The shipboard computer turns on the CTD through the modem radio link, controls the winch and line puller for the deployment and recovery operation, recovers the CTD data and puts the underwater unit into sleep mode between profiles. The software runs on an Intel 486, 33 MHz computer under Windows 3.1.

The computer program evaluates a mathematical model that describes the forces on the underwater body and the line during all stages of deployment and start of recovery. A typical screen is shown in Figure 4. The user enters the vessel speed, the winch speed and the target profile depth. The program computes the length of line that needs to be paid out to achieve the target depth. At higher vessel speeds, the length of line will be limited by the maximum tension that occurs when recovery of the fish begins. The program computes this tension based on the drag coefficient, the diameter and the length of the line paid out and the ship speed.

With the current version of the software, the operator needs to enter a separate program in order to wake up the computer in

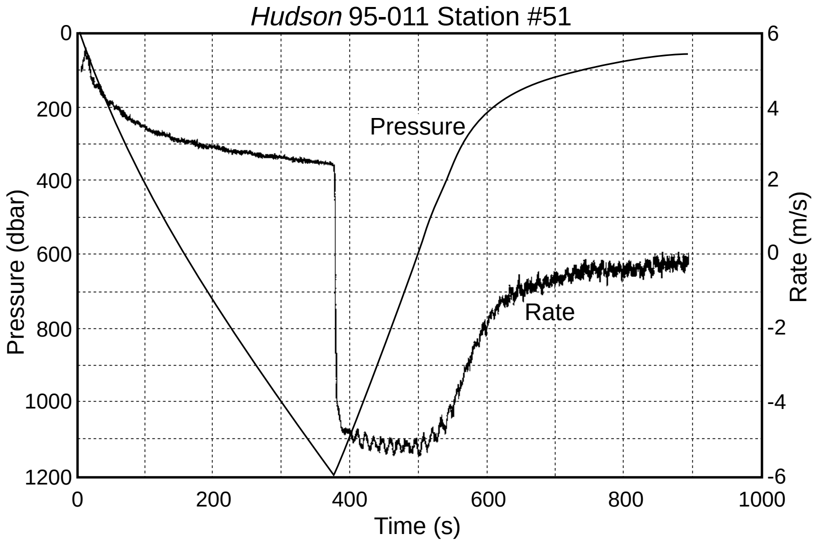


Figure 5: Depth and Rate versus Time for a cast to 1200 m at 10 knots (CSS Hudson*, June 1995).*

the sea unit and start the CTD. Then, returning to the winch control program, a single start switch starts the entire deployment and recovery cycle of the winch and line puller. The operator can terminate a profile at any time by activating an emergency stop button on the computer screen. This stops the line puller or the winch and applies the brake to the winch. An emergency stop switch mounted on the hydraulic power unit by the winch accomplishes the same action.

Ultimately, we see a software package that would reside in a computer on the bridge of a volunteer-observing-vessel. This computer would be interfaced into the vessel navigation system and hence know the vessel speed through the water. It might even know when profiles are to be taken and simply ask the officer of the watch whether it is okay to take a profile at this particular time. The shipboard computer would then carry out the entire operation including the creation and transmission of a Temperature/Salinity Code (TESAC) message describing the temperature/salinity profile.

At Sea Results

The prototype system was used on two WOCE cruises (Oct./Nov. 1994, Jun./Jul. 1995) in the Newfoundland Basin of the Northwest Atlantic on CSS *Hudson*. The system had undergone engineering trials on two previous cruises on CSS *Parizeau*. During the course of the October cruise, seventeen CTD profiles were obtained using the system at ship speeds ranging from 7.8 to 13 knots (Fig. 5). The system performed well; however, it was not sufficiently mature to allow the regular watchkeeper access to its control software. We were pleased that neither the chief officer and the bosun expressed concern about the stern plates of CSS *Hudson* and in fact admired both the design and the execution.

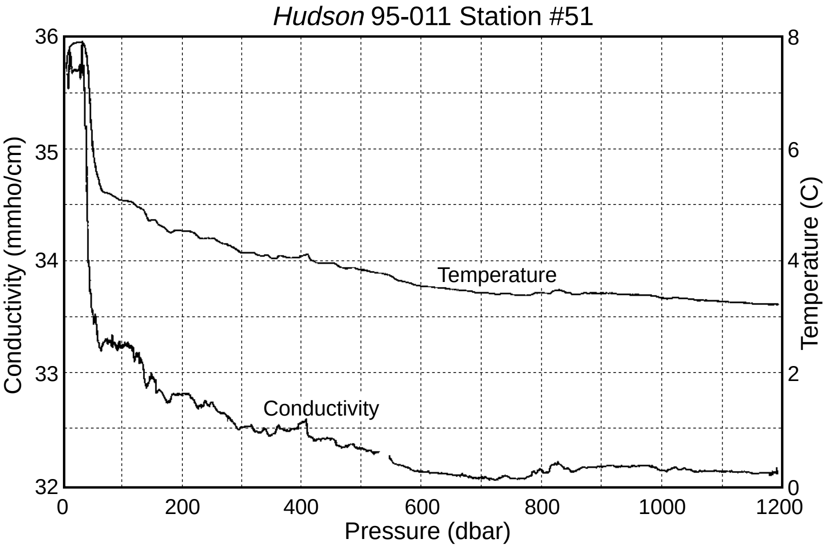


Figure 6: MV-CTD cast to 1200 m obtained at vessel speed of 10 knots showing Temperature and Conductivity versus Pressure.

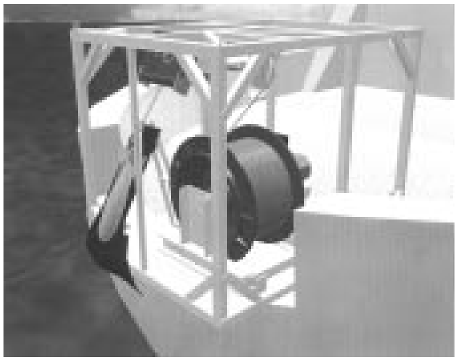


Figure 7: Computer-rendered view of the second generation MV-CTD deck unit.

We had concerns that the conductivity sensor would be affected by being mounted within a fish constructed of brass and in close proximity to the aluminum tail shroud protector. This was tested by suspending the fish containing the CTD and its associated electronics 1.3 m beneath our Seabird deep sea CTD system and taking two profiles to 600 m. The salinity profiles obtained by the fish with the FSI CTD where only different by an offset of 0.06 Practical Salinity Unit (PSU).

During tests in November 1994, it was discovered that under reduced vessel speed (and rough sea) conditions, it was necessary to reduce the line pay-out rate to avoid line tangles. As a result, speed control will be built into future versions of the control software. This is an important feature because we observed that we could continue to collect profiles with this system when the vessel was hove to due to weather conditions.

In June 1995, a longer cable (3000 m) was used and three casts at ten knots reached 1100-1200 m (Fig. 6). On the forth cast, the line parted and the fish was lost early in the cruise. A stronger line and a shock absorber will be used to prevent reoccurrence.

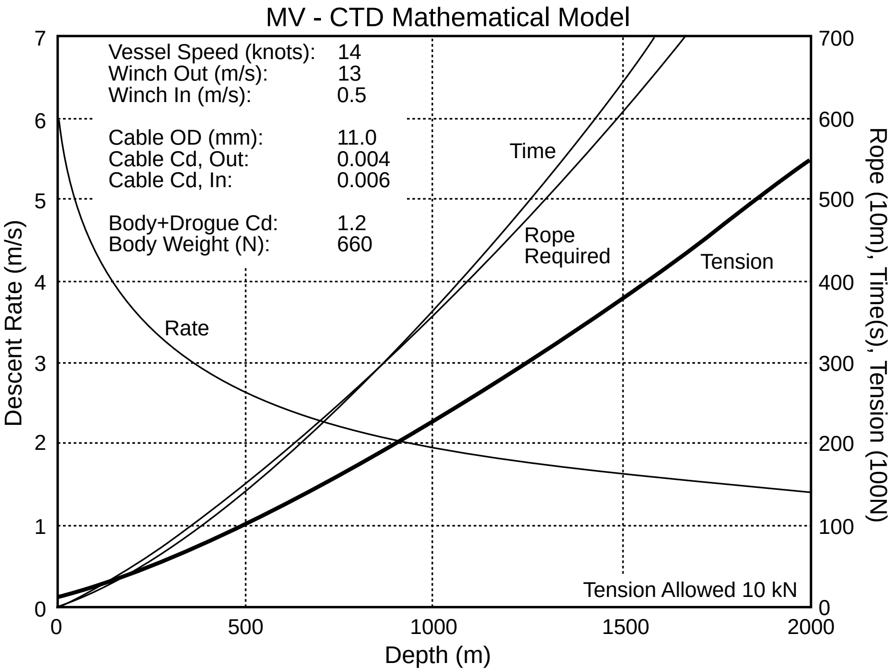


Figure 8: Predicted performance at 14 knots. A cast to 500 m will require 1600 m of line which will result in a line tension of 10.5 kN at the beginning of the recovery.

Second Generation

The design of the second generation system is underway. A computer generated representation is shown in Figure 8. All the components are integrated in a single frame which will simplify the transportation and installation on all ships. The width and height are such that it will fit inside a standard container for shipping. In order to accommodate the short distance between the winch and the line puller, the winch is moved back and forth on tracks in synchronism with the line being spooled on the drum.

The new line will be an electromechanical cable capable of transmitting the data from the CTD as it is being collected. This benefit and the elimination of the radio modem and batteries justify the extra cost of the cable. A mathematical model shows (Fig. 7) that at 14 knots, a cast to 500 m is possible with a maximum tension in the line of 10 kN.

In future years, this system will be used on our vessels to obtain upper ocean data as they travel to and from working areas in the course of a wide variety of research programs.

Acknowledgments

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Reference

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