WG-CEMP-87/15

ARCHIVAL AND SATELLITE-LINKED DATA RECORDERS

R.D. Hill
(USA)

Abstract

This paper provides an overview of currently-available data recorders for use in research on marine animals. These recorders are deployed on freely swimming animals and gather data on aspects of an animal's diving behaviour. The records can be recovered in one of two ways : the data recorder must either be recovered intact, or the data recorder must be capable of disseminating its data via a radio link, such as the ARGOS satellite system. Recorders can be further subdivided into raw-data and processed-data recorders. Raw-data recorders keep a complete record of the diving parameters of interest and thus produce extensive records, whereas processed-data recorders only report summary statistics which may be quite brief. Due to the limited data-handling capacity of the ARGOS satellite system, most satellite-linked recorders will necessarily report processed data.

Résumé

Ce document présente une vue d'ensemble des enregistreurs de données actuellement disponibles et pouvant être utilisés dans les travaux de recherche sur les animaux marins. Ces enregistreurs sont utilisés sur les animaux nectoniques et permettent de recueillir des données sur certains aspects concernant la conduite de plongée d'un animal. Les enregistrements peuvent être récupérés de deux façons : l'enregistreur des données doit être récupéré intact, ou bien il doit être capable de disséminer ses données par une liaison radio, telle que le système de satellite ARGOS. Les enregistreurs peuvent être également divisés en enregistreurs de données brutes et en enregistreurs de données traitées. Les enregistreurs de données brutes conservent les relevés complets des paramètres de plongée présentant un intérêt et produisent ainsi des relevés abondants, alors que les enregistreurs de données traitées ne fournissent que des statistiques récapitulatives qui peuvent être assez brèves. Vu la capacité de traitement limitée du système de satellite ARGOS, la plupart des enregistreurs reliés à un satellite ne pourront procurer que des données traitées.

Resumen

Este documento provee una reseña general de los registradores de datos disponibles actualmente para uso en la investigación sobre animales marinos. Estos registradores son desplegados en animales que nadan libremente y recopilan datos sobre los aspectos del comportamiento de zambullida de un animal. Los registros pueden ser recuperados mediante una de las siguientes dos maneras : el registrador de datos debe ser recuperado intacto, o bien el registrador de datos debe ser capaz de diseminar sus datos a través de una conexión radial, tal como el sistema de satélites ARGOS. Los registradores pueden ser subdivididos además en registradores de datos en bruto y en registradores de datos procesados. Los registradores de datos en bruto mantienen un registro completo de los parámetros de zambullida de interés y producen por lo tanto registros extensos, mientras que los registradores de datos procesados sólo informan estadísticas resumidas, que pueden ser relativamente breves. Debido a la limitada capacidad de manejo de datos del sistema de satélites ARGOS, la mayor parte de los registradores enlazados por satélite necesariamente informan datos procesados.

Резюме

В этой работе дается обзор имеющихся в настоящее время регистраторов данных, которые можно использовать в исследовательских работах по морским животным. Эти регистраторы прикрепляются к свободно плавающим животным и собирают данные по различным аспектам их поведения ныряния. Зарегистрированные данные могут быть получены одним из следующих двух способов: регистратор данных должен быть получен обратно неповрежденным или регистратор данных должен быть способен передавать имеющуюся у него информацию по радио, например, через систему спутниковой связи ARGOS. Далее, регистраторы данных могут подразделяться на регистраторы необработанной и регистраторы обработанной информации. Регистраторы необработанной информации хранят полную запись представляющих интерес параметров поведения ныряния и следовательно выдают большое количество данных, тогда как регистраторы обработанной информации передают только статистическую сводку, которая может быть довольно краткой. В связи с тем, что возможности системы спутниковой связи ARGOS в плане передачи информации ограничены, большинство подключенных к системе спутниковой связи регистраторов по необходимости будет передавать обработанную информацию.

ARCHIVAL AND SATELLITE-LINKED DATA RECORDERS

Roger D. Hill
Wildlife Computers
20630 NE 150th Street
Woodinville, WA 98072 USA

This paper is intended to be an introduction into techniques of remote data acquisition of diving behaviour of marine animals. The discussion is divided into two sections : Archival Recorders, which are attached to the animal of interest and subsequently recovered together with the stored data, and Satellite-linked Recorders, wherein the instrument is attached to an animal and data recovery and/or geolocation are provided by the ARGOS Satellite system. Use of either type of recorder allows diving behaviour to be investigated 24 hours a day for periods of days to months with little or no intervention on the part of the investigator. Examples of uses of data recorders might include gathering information on foraging strategies such as feeding depth, dive durations, and diving surface time ratios, both between individuals and between years.

SECTION I. ARCHIVAL DATA RECORDERS

An archival recorder is an instrument which gathers data (.e.g. depth, temperature) about an animal of interest and stores these data until the animal is re-captured and the instrument is recovered. The data are then extracted from the recorder which may be re-useable. The earliest archival data recorders were of mechanical design and fall into two distinct categories : Raw-data recorders, and Processed-data recorders. More recently the electronic equivalents of these two types of recorders have become available.

A raw-data recorder is one in which the original data are recorded verbatim and thus the precise behaviour of the animal under investigation can be re-created. Processed-data recorders perform some manner of data reduction and report summary statistics of the animal's behaviour.

The archival recorders that have been deployed thus far generally measure the depth of diving animals, although they are not necessarily limited in this respect; units have been used which also measure swimming speed, sea-water temperature, and physiological parameters of the diving animal.

Mechanical Raw-data Recorders

This type of recorder is typified by the film time-depth recorder produced by Meer Instruments (1,2). This instrument records dive profiles onto photographic film : increasing pressure due to diving causes an arm containing a small light source to track across the width of the film while an electric motor advances the film at a steady rate. The film must subsequently be developed and the dive profiles digitized before any analysis can be performed. The instrument provides continuous data recording for approximately 11 days with a time of resolution of 30 seconds. The design's main advantage is good data integrity - nothing can destroy the gathered data unless the pressure housing is ruptured. The disadvantages are that the unit is large (250mm by 50mm dia.) and heavy (700g), and data recovery and analysis are labour intensive.

Mechanical Processed-data Recorders

These recorders have been pioneered by Wilson and Bain (3,4) and provide time-at-depth or time-at-speed records. The principle of both units is the same : a radioactive bead is made to move over a piece of photographic film as a result of the depth or speed stimulus. The longer the animal spends at a given depth (or speed), the greater the exposure of the film at the corresponding location. Thus the relative exposure of the film at different depth (or speed) locations provides a measure of the relative time spent at those depths (or speeds). These instruments are very inexpensive to produce and are small and light in weight, but they require careful analysis to extract the data which are generally approximate.

Electronic Raw-data Recorders

These instruments were pioneered by Hill (5) for physiological studies on Weddell seals in the Antarctic. They consist of miniaturized computers which sample data at pre-set intervals and store the data into memory (RAM) for subsequent recovery. The only currently commercially available unit is the Wildlife Computers Microprocessor Time-depth Recorder MK-III. This unit can store up to 256,000 depth readings, which is equivalent to one depth reading every 10 seconds for one month. Because the unit employs a computer to control the data sampling, certain decisions can be made by the computer about the data or the sampling environment to conserve memory. For example data sampling may be inhibited when the animal is hauled out onto a beach or ice-floe. The instruments can also be equipped with a temperature sensor to monitor environmental temperature. The advantages of these units over mechanical time-depth recorders are smaller size (150mm by 24mm dia.), lower weight (120g), more versatile data sampling, and longer record length. Data recovery and analysis are also simpler : data are transferred directly to a personal computer, and immediately ready for graphing or statistical analysis. The disadvantage of these units is that if the batteries fail, all collected data are lost. Further information is available in Appendix 1.

Two other similar instruments are being developed in Dr G. Kooyman's laboratory, and may become available to researchers at some future date. The first was developed by E. Ponganis and is slightly smaller than the Wildlife Computers instrument, but contains less memory (24K RAM vs. 256K RAM). The second is a very small instrument under development for studies on Murres by J. Croal. This unit will measure approximately 60mm by 40mm by 19mm and weigh only 25g. However, memory size will be limited to 8K RAM. Requests for further information on either of these units should be directed to Dr G.L. Kooyman, Physiological Rsearch Laboratory, Scripps Institute of Oceanography, La Jolla, CA 92037, USA.

Electronic Processed-data Recorders

These recorders offer the smallest potential size for electronic recorders because little memory is required to store data. Diving data are summarized into counts of either number-of-dives-to or time-spent-at several pre-defined depth categories. One unit is currently available (the Maret Maximum Depth Recorder (2)), and the other is expected to be available in the summer of 1989 (Northwest Marine Technology (MNT) Archival Tag). The two units reflect very different design philosophies. Maret's unit is re-usable with easily replaced batteries but provides only eight pieces of data - the number of dives to eight different depth ranges. The NMT instrument will be a one-use-only instrument and employ 32K RAM to provide multi-dimensional histograms (e.g., simultaneous categorization of dives by length and maximum depth) as well as brief records of raw data. Perhaps the most interesting feature of the NMT instrument is the onboard detection of sunrise and sunset times. These times can be used to determine the approximate location of an animal in the tropics. It is not known if such a system can be employed in the Antarctic where sunrise and sunset are difficult to determine. Both of these instruments are small and light in weight (particularly the NMT unit), but require either a dedicated read-out unit (Maret) or return to the manufacturer for read-out and location analysis (NMT). Further information on these units is provided in Appendix 1.

SECTION II. SATELLITE-LINKED RECORDERS

One of the major limitations of the archival recorders discussed in the previous section is that they must be recovered. Satellite-linked recorders overcome this problem by transmitting data through the ARGOS Stellite system (the only currrently available satellite for Antarctic work). This technique is not without its problems for marine animals, however, and the instruments which can use the ARGOS system on seals and whales are still under development. The second, and perhaps the most important advantage of satellite-linked recorders is the potential for

geolocation of the animal. The details of the ARGOS system and the transmission requirements for geolocation are discussed elsewhere, and this paper will discuss how those inherent limitations will affect the use of the ARGOS system for tracking and recovering data from marine animals. A recent workshop studied these problems in relation to large cetaceans, and is included as Appendix 2.

The transmission requirements of the ARGOS system require that 1 watt transmissions be used. This defines the size of the batteries required to provide such power in the Antarctic cold, and the minimum battery configuration has been determined to be three Lithium "C" cells. The smallest transmitter commercially available measures approximately 50mm by 80mm by 13mm (Telonica, Mesa, Arizona USA), so this makes the smallest complete instrument measure approximately 100mm by 100mm by 35mm after allowing for a pressure housing. Obviously this is too large for small penguins, but could be carried by all Antarctic seals and possibly by some whales (see Appendix 2 for discussion of attachment mechanisms for whales).

Obtaining Geolocation Data

The ARGOS system requires a minimum of three complete transmissions in one satellite pass before a geolocation can be determined. This presents no problem for a seal hauled out on a beach or ice-floe, but makes geolocation of any animal in the water difficult for the following reasons :

1. Three transmissions must reach the satellite. A message will not be received unless the antenna is clear of the water. Careful positioning of instruments is thus vital.
2. Partial messages are ignored by the satellite. This problem can be reduced by only sending the minimum data (four bytes). This makes the transmission as short as possible and reduces the chance of interruption by diving, breaking waves, etc.

3. Transmissions must span a period of 5-10 minutes. The minimum inter-transmission interval is 40 seconds. However three successive transmissions at this interval will rarely provide ARGOS with sufficient data to perform a geolocation; ARGOS requires transmissions throughout a pass of the satellite to geolocate reliably. The animal under investigation should thus spend at least five minutes at the surface or take short dives so that transmissions can be performed on successive surfacings. This could present a problem for certain animals whose diving behaviour is incompatible with these limitations (e.g., elephant seals).

Obtaining Diving Data

The message length of the ARGOS system (four to 32 bytes per transmission) makes transmission of raw data impractical; processed data are obviously required. If the processing can reduce the data to four bytes, then diving data can be recovered with no additional problems over those discussed for geolocation only. If, however, more data are needed, then the transmission can be expanded to 32 bytes. The penalty for this is that the transmission time is longer (1 second vs. 0.3 second) and thus the chance of interrupted transmissions is increased. This may make such transmissions from an animal in the water so unreliable that no data are recovered. At this time I would recommend that only minimum-duration (four byte) transmissions be attempted from pelagic animals.

Diving data can be recovered from seals by using an archival recorder coupled to a satellite transmitter. The archival recorder gathers and processes dive data from the seal when it is in the water and these data are "parcelled" out, 32 bytes at a time, when the seal hauls out onto ice or a beach. There are several ways that data can be compacted so that usable information can be gleaned from 32-byte transmissions. These include partitioning data into bits or nibbles (four-bit units) where possible, and equipping each animal with several identification codes so that more than one message can be transmitted per satellite pass. Such data organisation requires rather sophisticated computer manipulation in addition to the primary data reduction mentioned before under Processed-data Recorders.

The ideal instrument would be able to perform the function of transmitting archived data when the animal is hauled out in addition to providing geolocations when the animal is pelagic. If large amounts of data need to be transmitted, the "C" cells specified earlier may become inadequate and the package must grow to hold larger batteries. Such a unit could no longer be carried by a fur seal without affecting its behaviour and possibly its survival.

LITERATURE CITED

(1) GENTRY, R.L. and G.L. KOOYMAN, eds. 1986. Fur seals : maternal strategies on land and at sea. Princeton University Press, Princeton, New Jersey, 291 pp.

(2) KOOYMAN, G.L., J.O. BILLUPS and W.D. FARWELL. 1982. Two recently developed recorders for monitoring of diving activity at sea. In : MacAlister, A.G. and I.G. Pride (eds.), Experimental Biology at Sea, Academic Press, New York.

(3) WILSON, R.P. and C.A.R. BAIN. 1984. An inexpensive depth gauge for penguins. J. Wildl. Manage., 48(4) : 1077-1084.

(4) WILSON, R.P. and C.A.R. BAIN. 1984. An inexpensive speed meter for penguins at sea. J. Wildl. Manage., 48(4) : 1360-1364.

(5) HILL, R.D. 1986. Microcomputer monitor and blood sampler for free diving Weddell seals. J. Appl. Physiol., 61(4) : 1570-1576.

(6) CAIRNS, D.K. et al. 1987. Electronic activity recorder for aquatic wildlife. J. Wildl. Manage., 51(2) : 395-399.

Table 1. Comparison of raw- to processed-data recorders

Raw	Processed
Retains original data	Stores summarized data
Few assumptions about diving behaviour prior to deployment	Requires prior knowledge of diving behaviour to gain maximum information
Generally larger	Generally smaller
Anomalies or malfunctions may be easily identified	Anomalies or malfunctions impossible to recognise
Potentially massive amount of data requiring subsequent graphing and analysis	Small amount of data requiring little further analysis

Table 2. Simple processed-data diving recorders (all can be "home-made")

	Penguin depth	Penguin speed	Time-budget recorder
Dimensions (mm)	70x45x10	45x12 dia	35x25x18
Weight (g)	30	5	7.5
Medium	film & radio-active beads	film & radio-active beads	digital watch
Cost	< US$ 10	< US$ 5	< US$ 20
Data recovery	develop film	develop film	direct obs
Reference	(3)	(4)	(6)

Table 3. Complex archival diving recorders

Supplier	Meer	Wildlife Comp. I	Wildlife Comp.III	Kooyman Ponganis	Kooyman Croal	Maret	NMT
Size (mm)	220x50	140x65x30	150x25	150x25	60x40x19	125x29	100x17
Weight (g)	700	340	120	200	25	112	23
Medium	photo film	48K RAM	64-256K RAM	24K RAM	8K RAM	8 counters	32K RAM
Cost (US$)	2000	700*	1000-1300	*	*	2000	2500*
Data recovery	develop film & digitize	personal computer	personal computer	personal computer	personal computer	dedicated read-out unit	return to mfr

* not currently commercially available

Légendes des tableaux

Tableau 1 Comparaison des enregistreurs de données brutes et de données traitées.

Tableau 2 Enregistreurs de plongée simples pour données traitées (on peut fabriquer soi-même tous ces appareils).

Tableau 3 Enregistreurs de plongée complexes pour archivage.

Encabezamientos de las Tablas

Tabla 1 Comparaciones de los registradores de datos en bruto con los de datos procesados.

Tabla 2 Registradores de inmersiones de datos procesados sencillos (todos pueden ser de fabricación casera).

Tabla 3 Registradores de inmersiones de archivo complejos.

Заголовки к таблицам

Таблица 1 Сравнение регистраторов необработанных и обработанных данных.

Таблица 2 Простые регистраторы обработанных данных о поведении ныряния (все регистраторы можно сделать самим).

Таблица 3 Сложные архивные регистраторы данных о поведении ныряния.

Wildlife Computers

APPENDIX 1

Roger D. Hill, D. Phil.
Suzanne E. Hill, Ph. D

E. 150th Street • Woodinville, WA 98072-7641 (206) 881-304

Microprocessor-controlled Time-Depth Recorder MK-III

General Description

The Wildlife Computers time-depth recorder is a miniature computer designed to gather data on depth, temperature and up to one further user-defined variable. Data are sampled at user-specified time intervals and stored into memory. These stored data are transferred to a personal computer via an inexpensive serial interface when the instrument is recovered. The instrument is mounted in an anodized aluminum pressure housing, and includes a conductivity switch so that data sampling can be inhibited when the animal hauls-out onto a beach or ice floe.

Technical Specifications

» Sampling rates from 1 per second to 1 per 255 minutes; specified by user at time of deployment.

» Crystal controlled clock to ensure accurate time-base.

» Conductivity switch to determine haul-out periods.

» Up to 8 different sampling protocols may be defined which are invoked under specified conditions of depth and/or conductivity (in/out of water).

» 3 standard depth ranges:
0 - 250 m, resolution 1 m
0 - 500 m, resolution 2 m
0 - 1500 m, resolution 6 m

» Unit may be cycled on and off to extend sampling period. Cycle periods, from minutes to days, are specified at time of deployment.

» Memory size from 64 KBytes to 256 KBytes.

» Wide operating temperature: -20°C to +35°C.

» Simple serial interface to personal computer at rates from 300 to 38,400 baud.

» Full documentation of data format to enable user to write analysis software.

» Sufficient power to take 1 million readings and store up to 256 KBytes for > 1 year.

» Units optionally provided with 2 depth ranges to provide wide depth range with higher resolution at shallow depths.

» Optional temperature channel: -5°C to +20°C, resolution 0.1°C.

» Standard housing of anodized aluminum; optional titanium housing available (approx. 200 g).

» Size: 150 mm by 25 mm diameter.

» Weight: 120 g (standard housing).

» Prices from US$ 1000 for 1 channel, 64 KByte instrument.

» Specialized variations can be produced; contact us.

MARET CONSULTING SERVICES

Creative Approaches to Biomedical Engineering, Environmental Research, Chronobiology, Holistic Health and Sports Medicine

APPENDIX 2

H. Maret, M.D.
dent

MAXIMUM DEPTH RECORDER

General Description

The maximum depth recorder is a miniature, digital, eight compartment recorder that stores either the number of times that a preset series of pressure thresholds have been exceeded or the total duration of time spent at or below preset depth thresholds. Every time that the output of a precision pressure transducer exceeds the pressure threshold of any of eight preset and equally spaced compartments, a new count is incremented in these compartments thus creating a histogram plot. The instrument may also be used in the Time-At-Depth mode so that the total time spent at each particular depth is recorded in ten second increments.

The instrument is deployed as a long term data recorder and is useful in gathering physiological and ecological information on the diving behaviour of marine mammals and birds. It may also be used as a safety monitor in human dives where it is of interest to monitor the total time at depth for any particular diver. The instrument must be recovered from the animal or man, but data readout can be effectively accomplished within a few minutes by connecting two ribbon cables to an external data processor. The instrument has been successfully used in the field on seals and penguins in the Antarctic.

Features and Specifications

* 22 Integrated Circuits, 1 Miniature Crystal. All integrated circuits are surfaced mounted construction for increased reliability, capability of future repair, small size and low weight.

* Timing is crystal controlled for stable time-base frequency generation.

* Anodized, aircraft quality, aluminum pressure vessel and bulkhead.

* Wide operating temperature: -20° to $+35^{\circ}$ Centigrade.

* 3 multi-layered circuit boards in a stacked construction for maximum component density.

* Battery box made from polycarbonate with gold plated contacts for increased reliability.

* System connection to processor via two ribbon cables terminated with 14 pin gold-plated dual-in-line connectors. Replacement interconnection cables are inexpensive standard electronics stocked items.

* Dual Operation: Modes of "Time-at-Depth" or "Events-at-Depth" available. One mode preset at the factory but mode may be changed at a later date.

9865 Mozelle Lane • La Mesa, California 92041 • (619) 698-9504

MAXIMUM DEPTH RECORDER, Page 2

* Low power CMOS design for a minimal power consumption during data acquisition. Unit goes into power conservation mode when data acquisition time exceeds a preset Time-Out period. This prevents total battery exaustion and possible loss of data from memory.

* Time-out period is preselectable and hardwired at the factory in three day increments from 3 to 93 days.Time-out period may be changed at later date.

* Light weight: 3.5 ounces (4.0 ounces with 6 lithium batteries)

* Small Size: 4.95 inches long, 1.15 inches in diameter.

* Batteries: 6 Lithium coin type batteries, Panasonic No. BR-2325. Total battery pack capacity 9 volts at 300 milliamperes-hours. Lithium batteries have extremely high energy density, long shelf life and excellent low temperature operational characteristics.

* Recommended transducer is Entran EPN series. These high sensitivity pressure transducers can be ordered in full range at 5, 15, 25, 50, 100, 250, 500, 1000, 2500, 3500 or 5000 psi. They can normally withstand two times their rated pressure without damage.

* Instrument operates in pulsed mode with a 16 msec transducer on-time. Pulse repetition rate is 10 seconds in Time-At-Depth mode and also in Event mode when not in dive, one second sampling rate when in Dive mode.

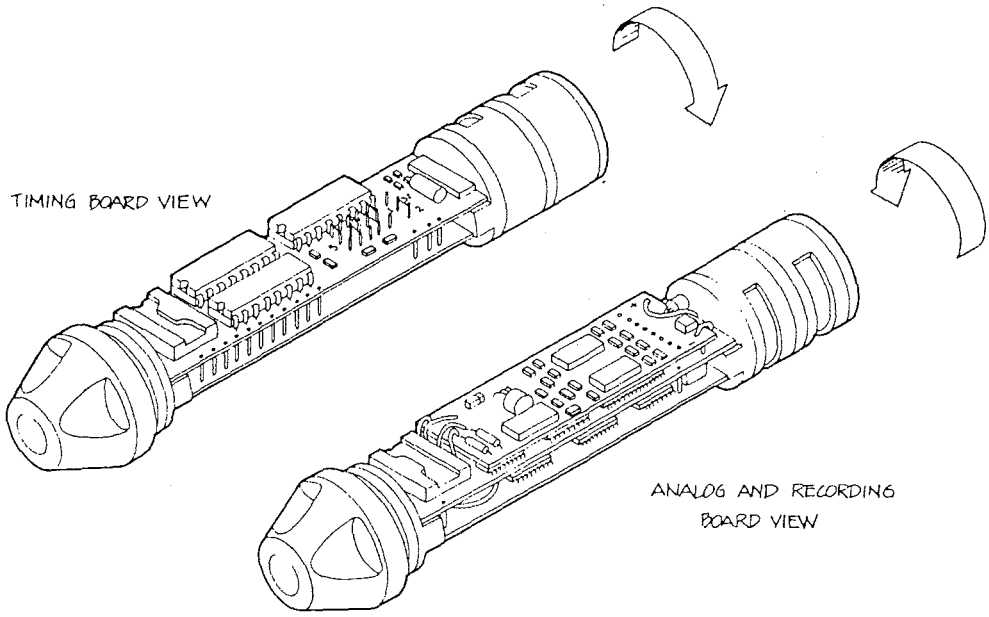
* Calibration to pressure station via a special screw-in connector with built in O-Ring, Swagelock No. B-200-1-OR.

PRICE

Quantities:		Deliveries:
1 - 2	$2,000.00	10 Weeks upon
3 - 5	1,900.00	Receipt of order
6 - 10	1,800.00	

DIGITAL READOUT PROCESSOR

Order Model MDR-Processor Mk.II. This unit is also required to calibrate the instrument. Specifications upon request. Cost is $2500.00



MAXIMUM DEPTH RECORDER

Recorder deployed on Gentoo penguin in the Antarctic.

APPENDIX 3

Product Preview

Archival Tag for Marine Animals

The Archival Tag is intended to gather, process, and record environmental data from which animal behavior can be deduced. In favorable cases the results can include a track of geographic position. The unit is presently under development, and the specifications given below are targets. Potential users who have additional requirements are encouraged to contact NMT, Inc.

Data Taken:

Pressure	0 - 500 Meters depth
Temperature	-5 to 35 Celsius
Light (460NM)	5 Decades including full sun
Auxiliary Sensors	A.C. conductance

Light intensity is measured at an optical diffuser on a stalk extending from one end of the unit. Temperature is measured at the end of the stalk and also internally to the unit. Auxiliary resistive sensors may be connected, and will be excited with A.C.

Onboard Processing:

Algorithms are provided for determining time of sunrise and sunset, and for characterizing the temperature structure of the upper ocean. User-defined programs may be included to expand the pre-defined capabilities.

Data recording:

N-dimensional histogram, time series, and telescoping time series options are provided. User programs may define others.

Memory Size:

32K Bytes user space.

Lifetime:

Multi-year.

Physical Details:

Diameter 17mm, length 100mm, neutrally buoyant. Case is hermetically sealed, corrosion resistant, and biologically compatible for implantation.

For further information, contact Northwest Marine Technology, Inc., Shaw Island, Washington, 98286, USA. Telephone (206) 468-3375