

MONITORING PENGUINS AT SEA USING DATA LOGGERS

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ABSTRACT

The activity of four penguin species at sea was studied using new data loggers. One unit was fixed to the bird's backs and recorded swim speed, swim heading and dive depth from which the three dimensional movements of the birds at sea could be constructed by vector calculations. This unit additionally recorded sea temperature and light intensity. A further, single-channel logger was ingested by the birds and recorded stomach temperature during the periods at sea. Drops in stomach temperature were indicative of prey capture and could be ascribed to specific localities.

INTRODUCTION

Transmission telemetry has been used with great success for a number of years to determine location and, more recently, physiological data from free-living animals. There are, however, certain conditions under which transmission telemetry is difficult or impossible to use. Such problems stem from radical signal attenuation by the medium between transmitter and receiver so that such large power packs must be used that the behaviour of the transmitter-carrying animal is changed to an unacceptably large degree. This problem is well illustrated by penguins which forage at sea many kilometres from land in a medium which attenuates radiowaves within a few metres and sonic signals within tens

of metres. Here, attempts at radio-telemetry are only successful when the birds are foraging close to their breeding colonies (Trivelpiece et al. 1986) or can be followed closely by boat (Heath and Randall 1989). Other than those satellite transmitters (e.g. Sadleir and Lay 1990), which have no range limit imposed, are so large that birds are unlikely to be able to forage as effectively as unequipped conspecifics (Wilson and Culik 1992) and thus do not adhere to normal foraging schedules.

In order to overcome this, penguin researchers have been developing archival units which log, rather than transmit, data on bird activity at sea. These data are recovered when the bird is recaptured at its breeding site. Initially, loggers stored data cumulatively without a time base (e.g. Croxall et al. 1988) but more recently, data on penguin foraging behaviour, such as swim speeds and dive depth, have been acquired using logging units which stored data against a serial time base (e.g. Kooyman et al. 1992a). Other units have successfully stored physiological variables, such as heart rate (Kooyman et al. 1992b) as a function of time. These advances are only possible as a result of advances in solid state technology which enables increasingly complex measuring systems to be made ever smaller.

We report here on the utilisation of two new types of data logger which we deployed on penguins and illustrate the potential of such autonomic measuring systems by presenting some preliminary results.

METHODS

Two types of logger were deployed; a multiple channel logger (MCL) and a single channel logger (EATL - Ein kanaliger Analoger Temperature Logger).

The MCL

The multiple channel logger (Driesen and Kern GmbH, D-2000 Tangstedt, Germany) recorded data in real time on a maximum of 12 recording channels (4 count channels and 8 analogue) with a memory of 64 kbyte. Using software it was possible to programme the unit to (i) vary the length of the measuring pulse (to reduce current consumption) (ii) record specified channels with 8, 10, or 16 Bit resolution (iii) alter the interval at which data were to be stored (between 1/32 s and 1 year) (iv) specify start and stop logging times (v) record mean values over specified periods and (vi) only record data during specific activities. The MCL was connected to sensors to detect dive depth (pressure transducer), swim speed (by counting the number of rotations of a paddle wheel), swim direction (semi-catanic compass combined with Hall generators to detect compass needle orientation with respect to the MCL housing) and, in some units water temperature and light intensity. The actual logging unit was the size of check card and 8 mm thick. This unit was incorporated together with the sensors and encased in resin. After being carefully hydrodynamically shaped so as to minimize drag in swimming penguins (estimated to be increased by ca. 20% at normal swimming speeds of 2 m/s) it weighed 200 g and had maximum dimensions of 140 mm (length) X 58 mm (width) X 28 mm (height).

The EATL

The EATL (Elkutec Electronic GmbH, D-8057 Eching bei Muenchen, Germany) was an analogue logger with a 32 kbyte memory designed to measure stomach temperature of endotherms. It had programmable sampling intervals of 8, 16 or 32 s and was housed within a titanium housing (100 mm X 25 mm diameter). The unit had absolute and relative accuracies of 0.8 °C and 0.1 °C, respectively.

Field deployment

Both units were used simultaneously on breeding penguins; African (*Spheniscus demersus*) at Dassen Island, Cape Province, South Africa (August/September 1991), and Gentoo (*Pygoscelis papua*), Chinstrap (*Pygoscelis antarctica*) and Adelie (*Pygoscelis adeliae*) at Ardley Island, South Shetland Islands, Antarctica (December 1991/January 1992). MCLs were attached to feathers on the penguins' backs using tape while the EATLs were first lightly greased before being introduced into the birds' oesophaguses and massaged down to the stomach. Units were generally removed after one foraging trip, the EATLs being recovered by stomach pumping (Wilson 1984).

RESULTS AND DISCUSSION

The combined use of internal and external logging units gives a broad overview of the internal workings of the animal in relation to its activity and the environment on a number of different scales.

Stomach temperature as indicator of activity.

In our case, it seems that measurements of stomach temperature could be a useful indicator of activity (both circadian and intradian) and possibly, when suitably calibrated, energy expenditure, since body temperature is likely to change somewhat as a result of muscular and other metabolic activities which produce heat. Results from the EATL in combination with a light sensor showed diurnal fluctuations in stomach temperature of African Penguins (Fig. 1) which appear to be linked to an intrinsic diurnal pattern but also varied as a function of environmental temperatures and insolation (Fig.1).

On a more reduced time scale, stomach temperature (in the absence of prey or water ingestion - see later) also varied as a function of whether the penguins were on land or in the water and as a function of swimming activity (Fig. 2). In African Penguins intense swimming activity caused stomach temperatures to rise from early morning resting values on land of ca. 39.5 °C to ca. 40.5 °C. In the absence of swim activity, however, stomach temperatures of birds at sea (water temperature 14.5 °C) dropped to less than 39°C (Fig. 2). This indicates that penguins in water do incur increased heat loss compared to when they are on land so that there is an equivalent associated energetic cost with being at sea. This has been also recently demonstrated by Culik et al. (1991) using gas respirometry on Adelie, Gentoo and Chinstrap Penguins. The effects of this appear to be negated by muscular heat production during swimming (Fig. 2) so that this would not be

relevant in foraging penguins but become an important consideration for birds actually resting at sea for long periods.

Stomach temperature as indicator of food ingestion.

Ingestion of food at ambient temperature by marine endotherms leads to substantial and rapid drops in stomach temperature (Wilson et al. 1992). The extent of these temperature drops in relation to their duration can be used to calculate the mass of prey ingested whereas the timing of the temperature drops indicates the precise time at which the prey were ingested (Wilson et al. 1992). Changes in stomach temperature following food ingestion have a characteristic profile of a precipitous drop followed by an exponential rise (Wilson et al. 1992). Thus, temperature changes resulting from feeding activity can be separated from changes that occur as a result of circadian rhythms or increased muscular effort (cf. Figs. 2 and 3).

Foraging parameters of penguins.

During foraging penguins swim and dive. This behaviour is conveniently described by three parameters which together are responsible for all active translocational movements: swim speed, swim heading and dive depth. Consideration of these parameters together enables the movements of the birds to be approximated by the use of vectors if the start and/or finishing position of the bird is known. For example, at specified data sampling intervals, changes in depth (vertical movement) can be equated with swim speed at this time to determine dive angles and overall horizontal movement. This horizontal movement can be appropriately converted into a swim course when swim direction is known. This process, termed 'dead reckoning', is often used by sailors for navigation. Information on the location of birds at sea together with other parameters enables researchers to examine animal behaviour and environmental conditions (when logged) as a function of locality. Fig. 3 illustrates this with the movements of a Chinstrap Penguin determined by this methodology. The foraging trip of this bird, which is typical, began with a series of shallow dives at swimming speeds in excess of 2 m/s. This resulted in the bird moving rapidly away from the island until it reached deeper water when it began systematic bounce dives to depths of up to 67 m. The bird caught prey (confirmed by stomach pumping to be krill (*Euphausia superba*)) at fairly regular intervals during the foraging trip (denoted by abrupt stomach temperature drops; see Fig. 3d) up until shortly after mid-day, after which no more food was ingested. During encounters with prey the behaviour of the bird changed substantially (Fig. 3e, 3f). 'V'-shaped searching dives, where swim speed and swim heading were maintained fairly constant, changed to 'U'-shaped dives with an irregularly-shaped bottom phase while swim speed and heading also became much more erratic. This presumably results from prey capture movements as the bird swam within the krill swarm (Fig. 3). Even subsequent to prey ingestion, the bird's movements were much less directional, presumably because the probability of prey detection was higher in the area where the bird had previously successfully hunted. After detection of the last krill patch, shortly after mid-day, the bird undertook a much less meandering course back to its breeding island. At this time, dive depths were shallow

(generally to less than 30 m) and swimming speeds were high (ca. 2.5 m/s). Changes in environmental parameters in time and space.

Penguins fitted with MCLs also logged water temperature, both as a function of depth and locality (determined via dead reckoning). For example, in the foraging area water temperature generally decreased with increasing depth (Fig. 4). Variation in water temperature overall and as a function of depth could mostly be ascribed to locality. Water temperature also varied with time during the course of our study. We are currently compiling the water temperature vs depth vs time of year data for the Maxwell Bay area in Antarctica so as to produce a three-dimensional picture of water temperature strata over time. This will be examined in relation to krill swarm distribution as determined by the penguins.

Future considerations

Our work with loggers demonstrates that this type of technology can be used to derive animal positions without supplementary information from transmitters. Long-term information on animal location is likely to become inaccurate, however, due to drift errors. Overall, however, knowledge of an animal's position can be particularly important since simultaneously logged animal activity as well as local environmental conditions can be put into perspective.

The logging units that we use for this study are still too large to be used on many species, but rapid advances in solid state technology will make it possible to produce loggers that are an order of magnitude smaller still. These units will be more readily implantable for measurement of physiological variables and, when attached to animals externally, are less likely to interfere with normal behaviour, which will make acquired results more meaningful.

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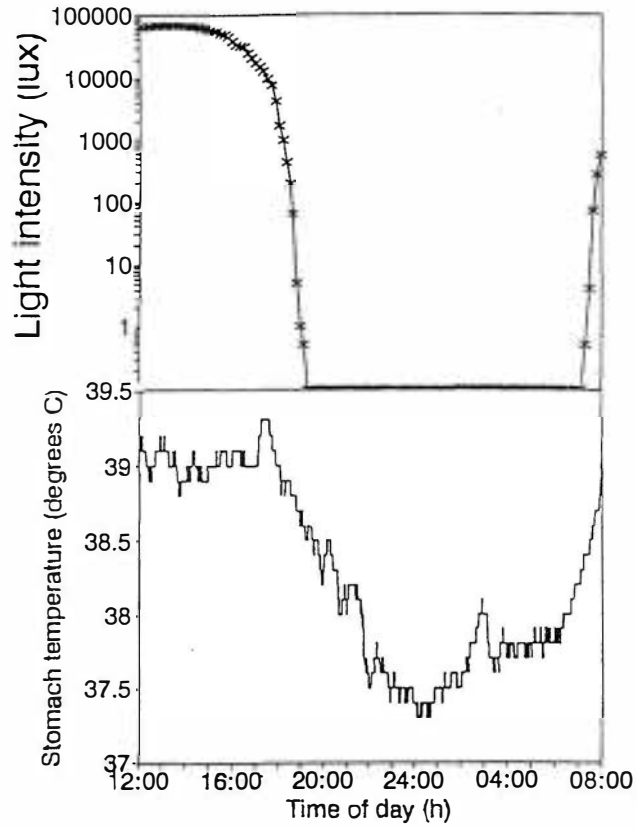


Fig 1. Changes in stomach temperature over time of an African Penguin incubating eggs in an open nest exposed to the sun. The insolation, measured in lux, and ambient temperatures are also shown. Birds incubating eggs in burrows sheltered from the sun show similar changes in body temperature although the temperature range is not as extreme.

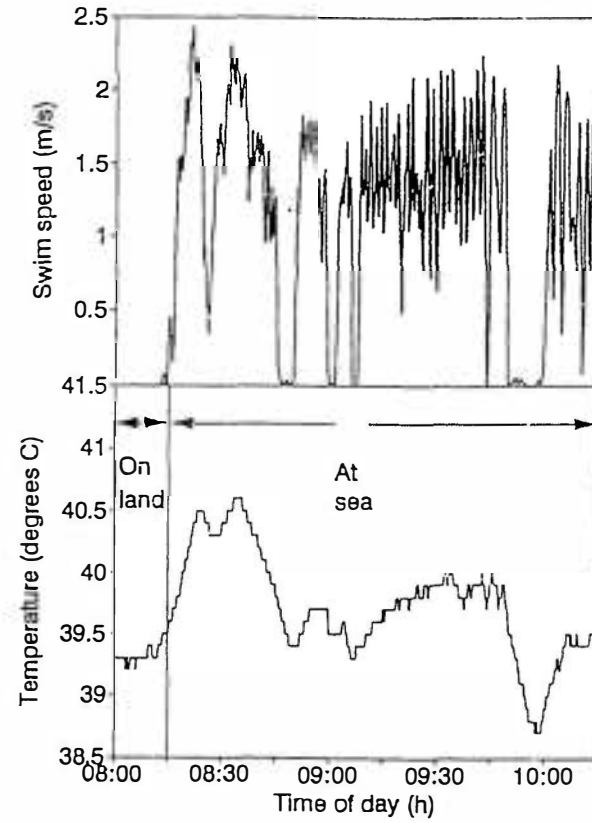


Fig. 2. Changes in stomach temperature in an African Penguin over time as a function of swim activity. The temperature data were recorded every 16 s. The data plotted for swim speeds come from a running mean of 10 points where normal sample interval was 5 s.

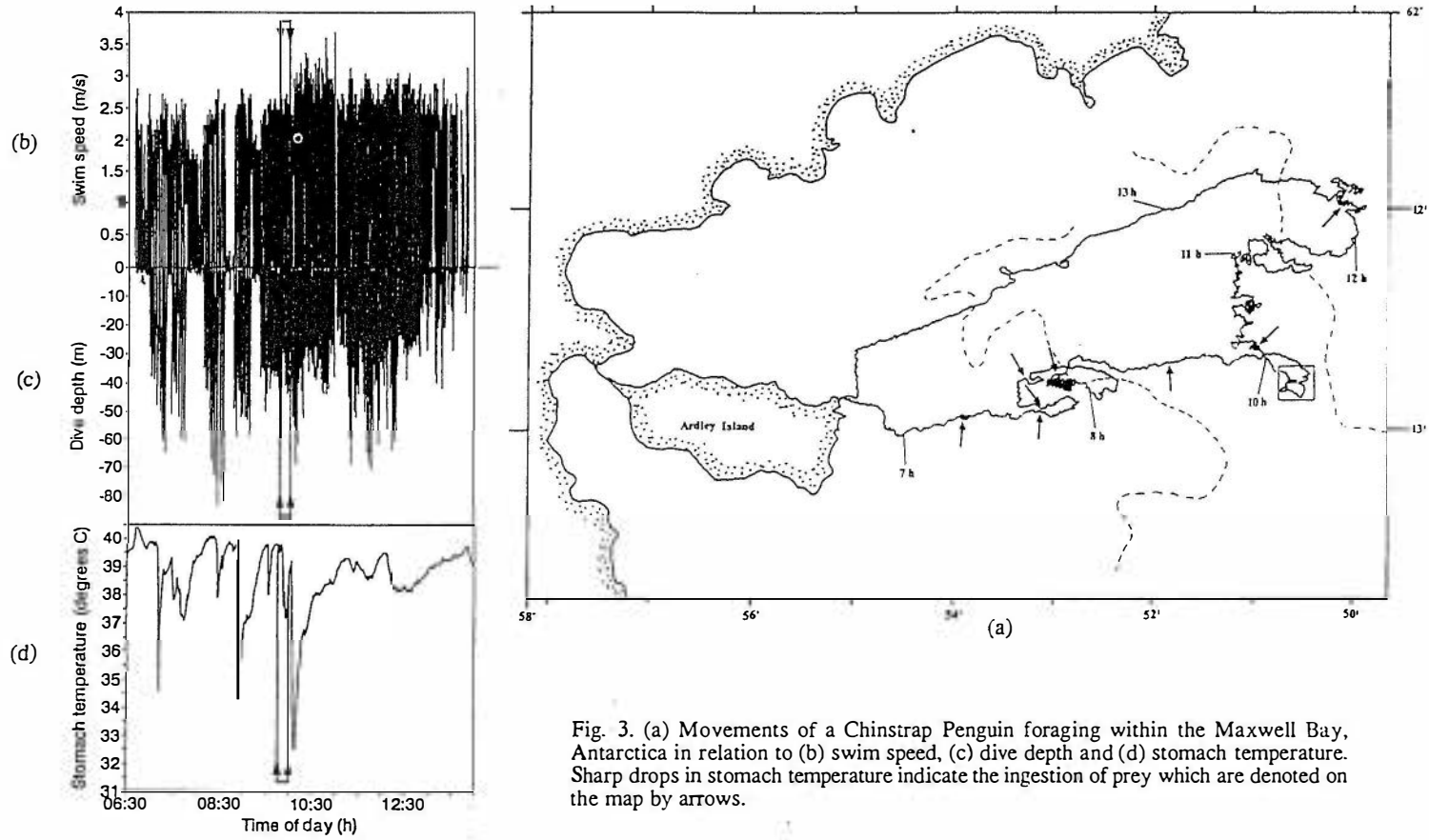


Fig. 3. (a) Movements of a Chinstrap Penguin foraging within the Maxwell Bay, Antarctica in relation to (b) swim speed, (c) dive depth and (d) stomach temperature. Sharp drops in stomach temperature indicate the ingestion of prey which are denoted on the map by arrows.

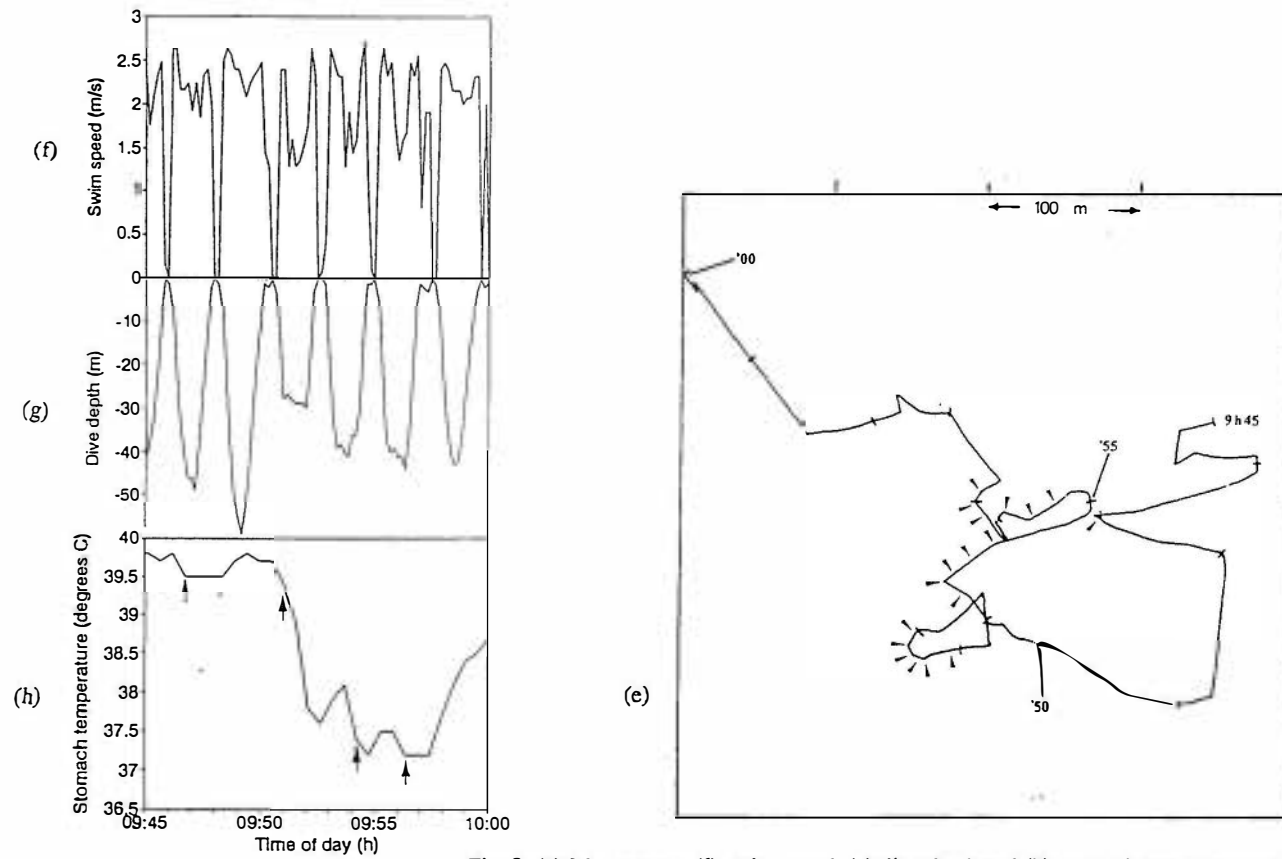


Fig. 3. (e) Movements, (f) swim speed, (g) dive depth and (h) stomach temperature of the Chinstrap Penguin (above) resolved on a much finer time scale (for position and timing in relation to the complete foraging trip see box and arrows in Fig. 3a-d). Arrows shown in the stomach temperature versus time graph show the timing of temperature drops associated with food ingestion.

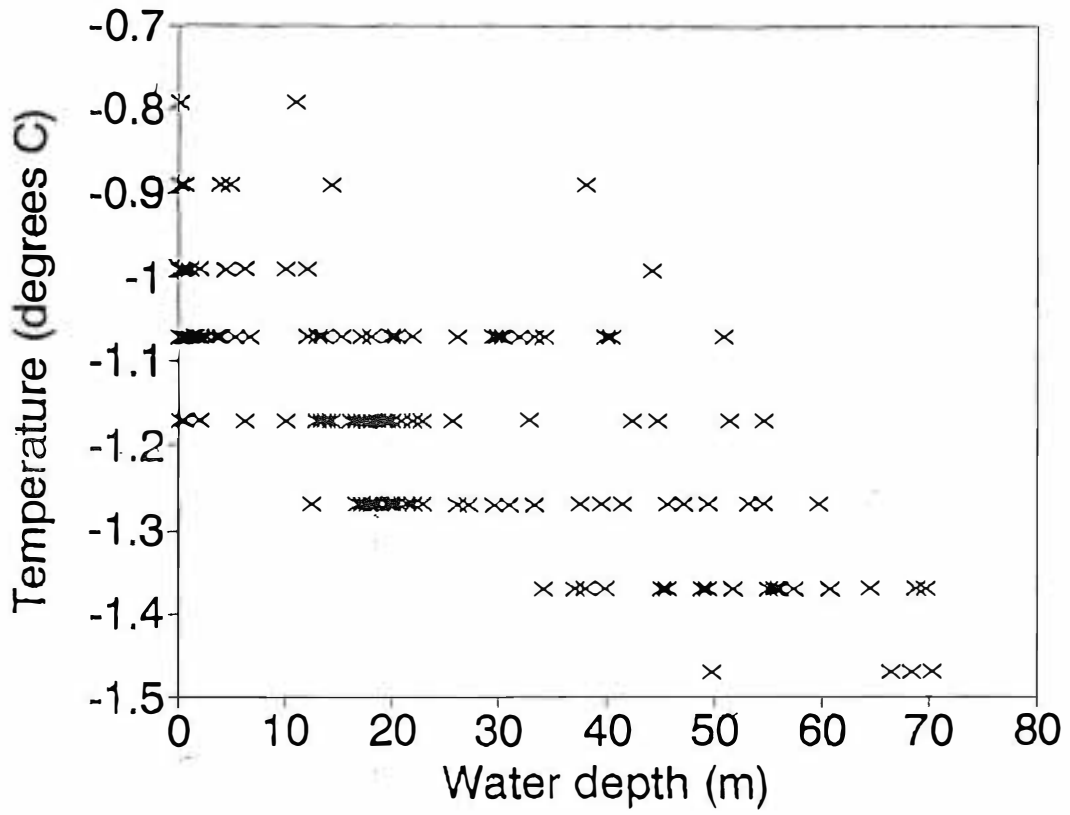


Fig. 4. Water temperature in the Maxwell Bay area of Antarctica as a function of depth as measured by a Gentoo Penguin wearing a MCL on 16 January 1992. Variability in the relationship comes from different measuring localities.