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Technical Note: Animal-borne CTD-Satellite Relay Data Loggers for real-time oceanographic data collection

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Abstract. The increasing need for continuous monitoring of the world oceans has stimulated the development of a range of autonomous sampling platforms. One novel addition to these approaches is a small, relatively inexpensive data-relaying device that can be deployed on marine mammals to provide vertical oceanographic profiles throughout the upper 2000 m of the water column. When an animal dives, the CTD-Satellite Relay Data Logger (CTD-SRDL) records vertical profiles of temperature, conductivity and pressure. Data are compressed once the animal returns to the surface where it is located by, and relays data to, the Argos satellite system. The technical challenges met in the design of the CTD-SRDL are the maximising of energy efficiency and minimising size, whilst simultaneously maintaining the reliability of an instrument that cannot be recovered and is required to survive its lifetime attached to a marine mammal. The CTD-SRDLs record temperature and salinity with an accuracy of better than 0.005 °C and 0.02 respectively. However, due to the limited availability of reference data, real-time data from remote places are often associated with slightly higher errors. The potential to collect large numbers of profiles cost-effectively makes data collection using CTD-SRDL technology particularly beneficial in regions where traditional oceanographic measurements are scarce or even absent. Depending on the CTD-SRDL configuration, it is possible to sample and transmit hydrographic profiles on a daily basis, providing valuable and often unique information for a real-time ocean observing system.

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1 Introduction

One of the greatest impediments to our understanding of ocean processes is a lack of in situ data from remote regions. As a consequence, there is currently a lack of ability to detect and monitor changes in oceanographic conditions in some regions known to be important climatically, and a shortage of data with which to challenge and validate climate models. Understanding the ocean's role in the climate system requires sustained sampling of the time-varying oceanic storage of heat and freshwater (Roemmich et al., 2004; Quadfasel, 2005). While the former reveals how the ocean absorbs and redistributes heat from the atmosphere, the latter reflects variability in precipitation and evaporation through salinity anomalies, with the added complexity of anomalies due to sea ice and glacial ice-related processes in the polar regions.

The Global Ocean Observing System (GOOS) is designed to fulfil these requirements (Alverson, 2008a), and necessitated the creation of special profiling floats with which to observe the temperature and salinity of the world's oceans down to 2000 m depth. The broad-scale near global array of profiling floats, known as Argo, has already grown to be a major component of GOOS. Deployments began in 2000 and, by the second half of 2007, 3000 floats were distributed over the global oceans. This array is providing about 100 000 hydrographic profiles and velocity measurements per year (Gould et al., 2004). The Argo array is designed for broad-scale ocean sampling at spatial intervals of hundreds of kilometres, greater than the size of eddies and boundary currents (Roemmich et al., 2004). Although the profiling float has enormous potential for these broad-scale ocean observations, it does not provide a complete observational strategy (Alverson, 2008b). Argo is designed to sample the oceans between

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60° N and 60° S and the profiling floats lack the capability to deliver real-time data from below the sea-ice zones in the polar regions. So it is essential that parallel advances are made in the measurement of air-sea exchanges and small-scale sampling for estimation of lateral fluxes. It is necessary to sample at higher spatial resolution in a "line-sampling" mode (i.e. section-based data distribution), resolving eddies and boundary currents for flux calculations, and to sample from ocean boundary to ocean boundary for flux integration. Research vessels lend themselves to the line-sampling mode, as reflected in the data collection strategies and ocean heat/freshwater transport estimates from the World Ocean Circulation Experiment and other comparable programmes (e.g. Ganachaud and Wunsch, 2000).

In this paper, we discuss and present recent advances in a novel technique that complements well the existing observing systems. Autonomous CTD-Satellite Relay Data Loggers (CTD-SRDLs) can be attached to marine animals, and report vertical profiles of conductivity, temperature and pressure to a maximum depth of around 2000 m (depending on species). The implementation of this technique has great potential to help populate remote and previously data-sparse regions (Fedak, 2004). Whilst the underlying concept is not new (Evans, 1970; Boehlert et al., 2001), CTD-SRDLs are the first animal-borne instruments that record full temperature and conductivity profiles, and enable transmission of these data in near real-time. This latter functionality is a key requirement for a fully-enabled ocean observing system, while the ability to return salinity data (derived from temperature, conductivity and pressure) is especially important in regions where the water column structure is dominated by salinity changes, e.g. the polar and subpolar oceans. The information returned from CTD-SRDLs is relevant not only to the study of physical structures of the oceans (Lydersen et al., 2002; Boehme et al., 2008a,b; Costa et al., 2008; Charrassin et al., 2008; Roquet et al., 2009; Meredith et al., 2009), but can also be useful for studying the ecology of the carrying animals (Lydersen et al., 2002; Hooker and Boyd, 2003; Lydersen et al., 2004; Charrassin et al., 2004; Biuw et al., 2007).

While the measurements returned by CTD-SRDLs are neither regular in terms of spatial and temporal coverage (compared, for example, to satellite measurements of oceanographic fields), these studies provide valuable in situ information about the subsurface structure of the ocean. The use of oceanic predators for remote data collection, although suffering from the inability to predetermine the locations of sample collection, can benefit from the ability of such predators to select foraging areas. Sampling is not uniform, but in many cases the predators act as "adaptive samplers" by targeting foraging areas, which are likely to coincide with many of the regions of most interest to biological and physical oceanographers (Guinet et al., 2001; Boehme et al., 2008b). This high resolution sampling across areas of strong gradients will help minimise spatial aliasing. Furthermore, migrations to and from these focal foraging areas are often highly directed, and regularly cross major ocean fronts, providing a combination of transect-type and mooring-like data (Boehme et al., 2008a,b; Costa et al., 2008; Meredith et al., 2009; Roquet et al., 2009). With careful selection of species, gender and age of the animals, as well as the geographic location and time of tagging, it is even possible to undertake focused, highly cost-effective oceanographic studies in regions that might be difficult, and therefore expensive to access in any other way (Nicholls et al., 2008).

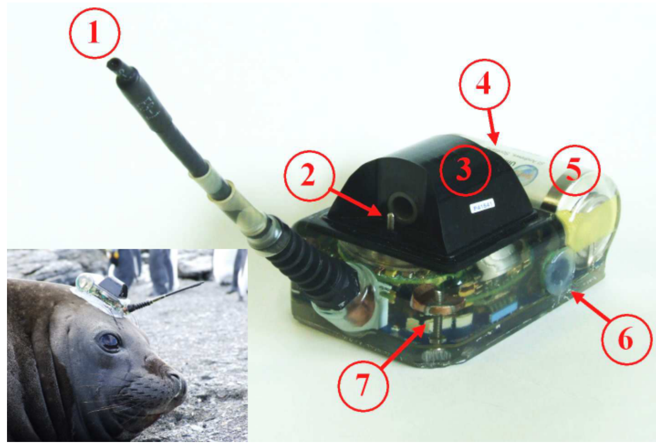

Fig. 1. Picture of a CTD-Satellite Relay Data Logger (CTD-SRDL) with antenna (1), temperature probe (2), inductive cell (3), pressure sensor (not visible) (4), battery (5), communications port (6) and wet-dry sensor (7). Insert: CTD-SRDL deployed on a southern elephant seal.

2 Design

The series 9000 CTD-SRDL (Fig. 1) is designed and built at the NERC Sea Mammal Research Unit (SMRU), St Andrews, UK. It consists of a 401 MHz RF unit and antenna for data transfer via the Argos system (Argos, 1996), a lithium-thionyl chloride (Li-$SOCl_2$) D-cell battery (LSH 20[1]) and a Hitachi H8/3048 microprocessor programmed to act as the data logger, data compression tool and to schedule data transfer. The CTD sensor package is built and calibrated at Valeport Ltd.[2], Devon, UK. Data from various sensors are collected when pre-programmed conditions of time and depth are met. Sampling algorithms onboard the CTD-SRDL detect the deepest point of a dive, and then begin rapidly sampling temperature, conductivity and pressure until the surface is reached. The limited Argos rate of data transfer and energy constraints (see Sect. 5) do not allow all data points to be transmitted. Therefore, a sub-set of pressure points with corresponding temperatures and conductivities are selected for transmission from these high-resolution data (see Sect. 4).

[1] http://www.saftbatteries.com
[2] http://www.valeport.co.uk/