# Deployment of CTD loggers on Kerguelen elephant seals in 2007

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## *Introduction*

To study the foraging ecology of elephant seals in relation to oceanographic conditions, the international "Southern Elephant seals as oceanographers" project has been launched since 2004, consisting in equipping elephant seals with CTD loggers (Fig. 1a) at four sub-Antarctic locations (South Georgia, Macquarie Islands, Antarctic Peninsula and Kerguelen Islands). These CTD loggers are capable of autonomously collecting and transmitting by satellite (Argos, CLS system) hydrographic data. In addition to their biological interest, the CTD profiles sampled in the remote Austral Ocean are of great interest for oceanographers. Currently, more than 8000 profiles were acquired south of 60°S (9 times more than obtained from floats and ships) and about 4500 profiles were obtained beneath the sea ice, in important regions for the deep overturning circulation study. Seals profiles were transmitted in near real-time to Coriolis from where they are distributed to the modelling and oceanographic communities, complementing data obtained from ships, satellites and floats.

During the austral summer 2007, 16 elephant seals from the Kerguelen Islands colony and 3 Weddell Seals from Adelie Land, Antarctica were equipped. This resulted in more than 4500 T/S profiles (Fig. 1b). Contrary to first deployment years where elephant seals mainly foraged close to the Antarctic continent, most 2007 seals stayed over the shallow platform of the Kerguelen Plateau or followed the Polar and Sub-Antarctic fronts eastward. On average, 2.5 profiles were transmitted daily by each logger. The logger operational lifetime ranged from 30 to 200 days (mean 90 days) and 6 loggers were still in operation on September 30th, 2007. The CTD loggers deployed in 2007 contained a newly designed CTD unit made by Valeport (UK) and were assembled at SMRU (St Andrews, UK). All the loggers were then statically calibrated in the new calibration laboratory of Valeport. The main novelty of the CTD unit consisted in the conductivity sensor being now completely pressure-housed with a titanium coat. A major step in salinity quality was therefore expected this year. In the following, we will present two calibration at-sea experiments performed prior to the deployment, before introducing the 2007 transmitted data set.

## *Calibration results from the at-sea experiments*

Prior to the deployment of the CTD loggers, two at-sea experiments were performed. The first one was performed in the Mediterranean Sea on 12 of the 16 loggers deployed at Kerguelen on board the R/V Tethys 2 and the second one was done on the 3 loggers deployed at Adelie Land on board the R/V Astrolabe in the Antarctic coastal water. Both experiments consisted in attaching the CTD loggers to a standard calibrated CTD (Seabird SBE25) and doing several dives for comparison purpose – 7 dives at ~400 m in the first case and 3 dives between 600 and 800 m deep in the second case. The thermohaline structure of mediterranean waters is characterized by slowly varying warm and saline deep waters (13-14 °C, 38.2-38.7 psu) separated from surface waters by a very strong thermocline found between 40 m and 70 m. Antarctic waters sampled during the second experiment are colder and fresher (-2°-0 °C, 34-34.65 psu). It is noted that the mediterranean structure encountered during the first experiment is very different from the one found where loggers are deployed. Yet, we will see that valuable information can be obtained from this experiment.

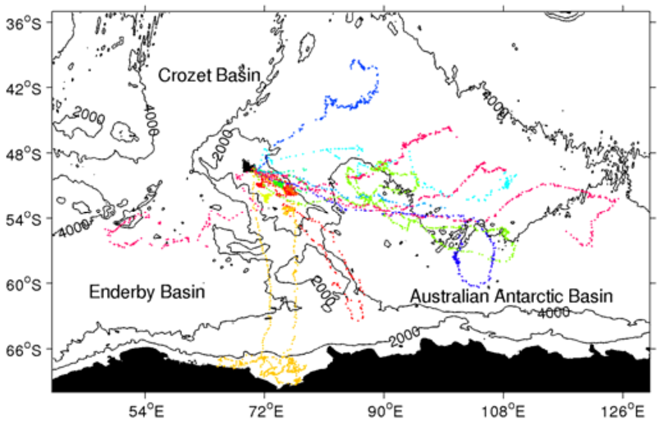


*Figure 1: (a) An elephant seal equipped with a CTD logger. (b) Position of the profiles transmitted by the 16 CTD loggers deployed at Kerguelen in 2007.*

The methodology was identical for both experiments. The CTD loggers sampled the water column during the ascent phase of each dive (speed: ~1 m/s) at a 1 s sampling rate and were attached upward to simulate best an elephant seal ascent. By attaching the CTD loggers to a SBE25, we aimed at referencing separately each of their sensor measurements – pressure P, temperature T and conductivity C – to reliable hydrographic measurements. To do so, we first needed to synchronize SBE25 measurements with CTD loggers one. This was done by using pressure as a proxy, because this sensor has a fast response time negligible in respect with 1 second. Once synchronized, the three sensors' responses could be analysed separately.

The comparison of the loggers' P sensor response with SBE25 provided excellent results, with the rms of the difference generally lower than 1 dbar. In some cases, a light bias was detected, which could easily be corrected using a linear function.

For T and C, we were interested in systematic biases and their relation to P. Thus we studied the difference between the CTD loggers and the SBE25 T and C series as a function of P. Firstly, we separately averaged loggers and SBE25 T (C) timeseries in 10 dbar bins. All bins where the ensemble rms was greater than an arbitrarily-chosen threshold (0.005 °C for T and 0.005 mS/cm for C) were discarded to ascertain that the difference was only considered in weakly stratified areas. Indeed, in stratified areas, characterized by strong vertical gradients of hydrological properties, time-lag differences between loggers and SBE25 sensors result in important non-systematic biases.

Two typical examples of the differences between SBE25 and CTD loggers T and C are presented, one for the Mediterranean experiment (Fig. 2, logger 10518) and the other for the Antarctic experiment (Fig. 3, logger 10555). Remarkably, T and C biases were very similar from dives to dives in both cases, which was very encouraging to further correct them. To investigate further the pressure dependance, the differences were fitted linearly. The mean standard error of the linear fit was only of 0.003 °C and 0.003 mS/cm, demonstrating the great similarity of biases from dives to dives for any given logger. The slopes for T varied from non-significant values (<0.01 °C/km) to lightly higher than 0.05 °C/km (Fig. 3). In the latter case, a correction of received data could be undertaken, consisting in removing the detected systematic bias from all T data.

While the slopes of C fits were generally weak (~0.02 mS/cm/km), C values were all negatively offseted, in both Mediterranean and Antarctic experiments. However, the magnitude of these offsets was clearly greater in the former experiment (mean -0.08 mS/cm) than in the latter one (mean -0.02 mS/cm). We are currently investigating the possible causes of this offset. We suspect problems in the calibration method used at the Valeport laboratory to scale C sensors,

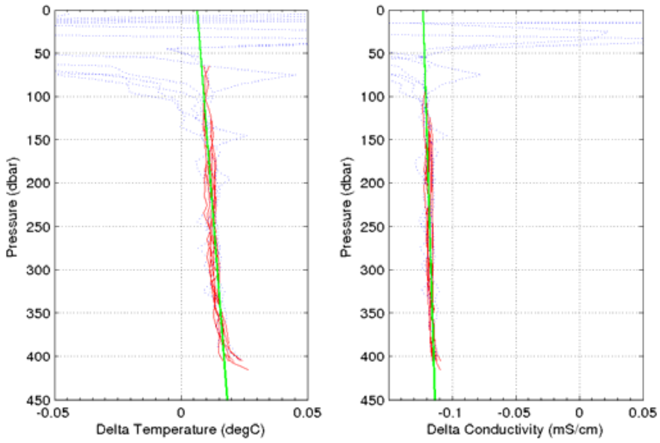


*Figure 2: CTD loggers versus SBE25 differences of T and C sensors response for the 7 dives of the 10518 logger performed in the mediterranean sea (dashed blue). Values used to calculate the linear fit are shown in red, and the linear fit is superimposed in green. See the text for details on the method of calculation.*

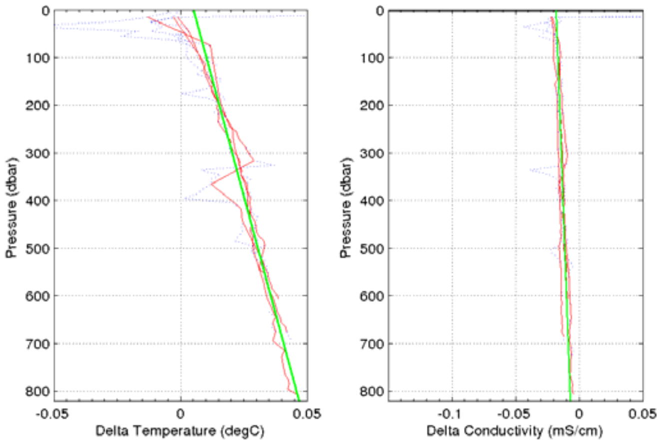


*Figure 3: Same as in Fig. 2, but for the 3 dives of the 10555 logger performed in the Antarctic coastal water.*

which may fail for the high C values found in the Mediterranean Sea (~45 mS/cm). Indeed, we recalibrated 4 loggers at the calibration laboratory of the SHOM and found significant discrepancies in C for values greater than 30 mS/cm, increasing with increasing conductivities. Unfortunately, the recalibrated loggers were not the same than those tested at sea, preventing us to be conclusive for the moment.

***The transmitted seal data set***

Due to the limited Argos system bandwidth, CTD data logged during an elephant seal dive can not be entirely transmitted. It is thus necessary to compress CTD data before transmission, which is done automatically by the logger micro-controller. Once compressed, hydrographic profiles are transmitted under the form of 18 T/S points (see Roquet et al., 2007, for a detailed description of the compression algorithm).

In Fig. 4, we show T/S profiles from the CTD logger 10518 super-imposed with historical CTD profiles from the same geographic area. The good superposition of both sources' profiles show the absence of significant offset in conductivity, in great contrast with the mediterranean experiments where the offset was greater than 0.1 mS/cm which corresponded to a salinity offset >0.1 psu. This is consistent with results of recalibration tests done at the SHOM laboratory indicating that this offset is probably conductivity dependant, increasing with increasing conductivities. Also it demonstrates the need for a post-transmission C offset estimation.

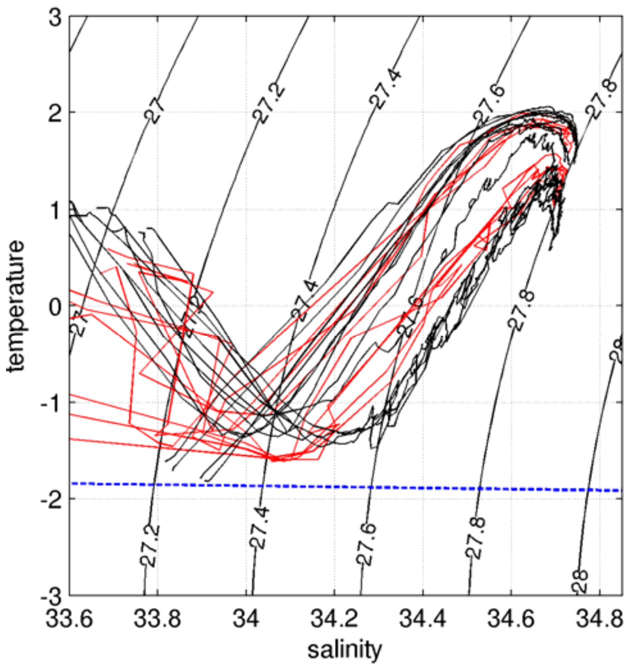


*Figure 4: Superposition of historical (black) and logger 10518 (red) T/S profiles sampled in the same region (61-65°S, 70-76°E). Both data sources' measurements are consistent, particularly in deep layers (upper right corner of the diagram).*

Several indirect methods to estimate the magnitude of the C offset in the transmitted data are possible. One method is to use the stable T-S relationships of deep waters to compare loggers and historical profiles as for example in Böhme and Send (2005) for Argo float salinities. This method is made more difficult for seals data than for Argo data because of the lower mean depth of seals profiles (~600 m against 2000 m for Argo) and the generally sparse distribution of historical profiles in Antarctic regions, yet it generally yields a valuable estimate (Roquet et al., in prep.). However, this method can be inadequate, particularly south of the Polar Front because deep water temperatures are almost homogeneous there and the associated T-S curves are nearly horizontal, rendering the T-S relationships highly ill-defined. Fortunately, in that case, we can benefit of the proximity of the stable and vertically homogeneous Circumpolar Deep Water from the surface to estimate roughly the magnitude of the C offset (Roquet et al., 2007).

Another way to explore is the inter-comparison of conductivities between CTD loggers when different seals crossed the same areas. In 2007, a great concentration of profiles is found over the shallow part of the Kerguelen Plateau and along 54°S in the Australian-Antarctic Basin. We may take advantage of this superposition of profiles to inter-calibrate the different CTD loggers.

## Conclusion

Since the earlier developments of the CTD loggers in 2003, several critical technical improvements have been achieved, leading to better accuracy of the CTD unit and a far better reliability of the whole logger. The last modification in date is the protection of the C sensor from pressure effects with a titanium coat. No important changes in the CTD unit conception should happen now, which should permit to provide an homogeneous interannual data set from now on.

Yet, some biases still exist and necessitate a rigourous calibration work, both before and after deployment. In addition to the static calibration done by Valeport, a recalibration in a laboratory of reference like the SHOM appears necessary as long as the discrepancies between both calibrations are observed. Testing loggers on field before the deployment also appear essential to estimate the loggers' overall quality and to correct possible pressure-dependant biases like for T.

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