ON THE VALIDATION OF HYDROGRAPHIC DATA COLLECTED BY INSTRUMENTED ELEPHANT SEALS

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ABSTRACT

To study the foraging ecology of elephant seals in relation to oceanographic conditions, a Satellite-Relayed Data Logger (SRDL) has been developed, which is able to sample temperature and salinity profiles during the foraging trips of seals. This device has the potential to provide detailed oceanographic information in logistically difficult areas at comparatively low cost, being therefore highly interesting for the oceanographic community as well.
Large efforts for calibrating and validating the huge amount of collected hydrographic data have been constantly made since the first deployments in 2004, as a necessary step to produce data useful for oceanography. When possible, at-sea experiments were performed on ships of opportunity before deployments on seals, consisting in comparing hydrographic profiles from SRDLs with reference profiles obtained simultaneously with a standard CTD. These experiments brought to light a satisfying repeatability of SRDL sensors but also the presence of systematic biases which should be corrected.
Here we present a calibration procedure to estimate and reduce systematic biases, which is applied to a seal dataset obtained in 2007. This set contains more than 3000 valid temperature/salinity (T/S) profiles, collected by 10 SRDLs around the Kerguelen Islands in the Southern Indian Ocean. The calibration procedure combines a calibration based on at-sea experiments with several delayed-mode calibration methods, based on comparisons of T/S profiles from SRDLs with available historical profiles (mainly CTD and ARGO profiles) or with each other (cross-comparisons). This calibration step is shown to be necessary to produce data useful for further oceanographic studies, allowing the production of a homogeneous dataset with an overall accuracy generally better than 0.02 °C for temperature and 0.03 for salinity.

1. CONTEXT OF THE STUDY

Satellite-Relayed Data Loggers (SRDL) with an integrated Conductivity-Temperature-Depth (CTD) have been developped by the Sea Mammal Research Unit (University of St Andrews), which autonomously collect and transmit hydrographic profiles (temperature/salinity) in near-real time via Argos satellites. Southern elephant seals Mirounga Leonina are very well suited for the deployment of these new loggers, because they dive continuously and at great depths. Moreover they undertake long foraging trip each years, exploring large areas of the Southern Ocean.
Deploying SRDLs on elephant seals allows biologists to better understand the seal foraging strategies in relation to the oceanographic conditions [1] and to explain the differences in population trends amongst the different colonies around the Southern Ocean [2]. In addition, the CTD profiles sampled in the remote Southern Ocean are of great interest for oceanographers. Indeed, temperature and salinity profiles are self-valuable, particularly in the remote Southern Ocean where data are sparse or even inexistent. In two years (2004 and 2005), more than 14,000 SRDL profiles were sampled at four sub-Antarctic locations (South Georgia, Macquarie Islands, Antarctic Peninsula and Kerguelen Islands), providing a nearly circumpolar description of fronts in the Southern Ocean [3]. Some of these profiles were sampled under the sea ice in winter. SRDL profiles have brought new information in several regions of the Southern Ocean, such as around the Antarctic Peninsula [4, 5, 6], the Kerguelen Plateau [7] or over the Antarctic shelf [8, 3]. These contributions are presented in the community white papers [9] and [10]. One important aspect of this methodology is the near real-time delivery of SRDL profiles using the Argos satellite system. Currently, seal profiles are transmitted in near real-time to the Global Telecommunication System (GTS) to be

assimilated in general circulation models such as the Mercator model for operational oceanography.
Large efforts for calibrating and validating the huge amount of collected hydrographic data have been constantly made since the first deployments in 2004. This work is necessary if we want to integrate them in global oceanographic databases to complement ship-based CTD, bottle and Argo profiles. In several sectors of the Southern Ocean, SRDL profiles are becoming a predominant input of data [3] and could induce noticeable biases in climatologies if not properly calibrated. As for Argo profiling floats, the targeted accuracy is of order 0.01 °C in temperature and 0.01 in salinity, although this level of accuracy is still difficult to reach as will be shown hereafter.

2. THE DATASET

This short paper introduces several methods and results related to the calibration and validation of a limited seal dataset, namely 10 SRDLs deployed on Kerguelen Islands in 2007 (Fig. 1). A detailed presentation of this calibration work should be the subject of a longer publication coming soon.
The seal dataset used in this study may be considered as somewhat representative of the wider SRDL-based dataset, in that the SRDLs are from the latest series deployed in a wide variety of sites since 2007. The accuracy statistics on hydrographic data quality here obtained may thus serve a a reference for subsequent analysis of other SRDL dataset.

3. AT-SEA EXPERIMENTS

At-sea experiments were performed prior to the deployment on seals. These experiments consisted in performing several casts with SRDLs attached to the same frame than a CTD used as a reference, thus enabling direct comparisons of hydrographic data logged by SRDLs with a reference. Biases could then be estimated from the difference between SRDL and reference sensor data. These tests were shown to be very instructive, as they provided important indications on the overall quality of SRDL sensors. In particular, a satisfactory precision (repeatability) of order 0.01°C and 0.01 psu could be demonstrated for each SRDLs. They also revealed the existence of two main sources of systematic biases, related to pressure effect and the external field effect.

3.1. Pressure effect

A pressure effect was detected on both the temperature and conductivity sensors, with a bias increasing linearly with depth. This effect could be efficiently estimated and subsequently removed from seal data using at-sea experiment comparisons.

3.2. External field effect

The external field effect is a classical feature of inductive conductivity sensor. Laboratory experiments on the sensitivity of conductivity to this effect are presented in [11]. The external field effect induces a salinity offset, with a magnitude depending on the presence of objects close to the conductivity sensor disturbing the external magnetic field. Once the configuration of the close environment of SRDLs is maintained constant, the salinity offset remains constant. This explains why the salinity offset is constant for each SRDL during the entire deployment period. Unfortunately, the external field effect cannot be corrected based on at-sea experiments, as the magnitude of this effect is generally different during the at-sea experiment and the deployment period. One important issue of the SRDL calibration is thus to estimate the salinity offset. This is done either by comparison with historical profiles (when possible), or using cross-comparisons between the different SRDLs.

4. THE LOWER CIRCUMPOLAR DEEP WATER METHOD

In some cases, SRDLs can be calibrated directly by comparisons with historical profiles. This is possible when a water mass with stable hydrographic properties is sampled. One such stable water mass in our study area is the Lower Circumpolar Deep Water, sampled by seals foraging south of the Southern ACC Front found at ~60°S.
Here we present the instructive case of SRDL #1. Several T/S diagrams are presented, both before and after the pressure correction, together with typical historical profiles from the same region (Fig. 2). The deep part of T/S diagrams, being their right part (where density is highest), show two local maxima, a maximum in temperature and then a deeper maximum in salinity. This latter maximum in salinity characterizes the Lower Circumpolar Deep Water, originating from the remote salty North Atlantic Deep Water. As a deep feature of the Southern Ocean, its hydrographic characteristics are very stable through time, especially the value of the salinity maximum (here between 34.73 and 34.74). The salinity maximum can thus be used as a reference to validate seal profiles.
With no pressure correction, the curvature of the seal T/S diagrams is too weak, yielding an abnormally saline water mass at depth and the absence of the characteristic salinity maximum. The pressure correction, which consists in removing a linear trend in salinity of slope 0.05 km^{-1} for SRDL #1, increases the curvature of the deep part of T/S diagrams. This in turn allows a good matching between seal and historical T/S diagrams, which would be otherwise impossible to achieve without the pressure effect correction. For the particular

case of SRDL #1, no additional correction was necessary after the pressure effect correction, indicating a zero offset in salinity. The good matching validates hydrographic data from the SRDL #1, giving confidence that the salinity accuracy for corrected SRDL #1 is on the order of 0.01.

5. CROSS-COMPARISON OF SEAL PROFILES

To estimate the salinity offset, a cross-comparison method can also be used, based on a least-square minimization of salinity differences between SRDL profiles. The cross-comparison method is able to provide an optimal estimate of the difference between the offset of two SRDLs when a sufficient number of close profiles are available. The proximity between two SRDL datasets, or equivalently their level of intertwining, can be objectively estimated from this method once the covariance between observations is modeled. In our particular case of the 10 SRDLs deployed at Kerguelen Islands, it was found that the use of the cross-comparison method on surface salinities over the low variability Northern Kerguelen Plateau (depth < 1000 m) was able to determine the salinity offsets for 7 out of 10 SRDLs. Yet, the offsets are given relatively to a reference SRDL which must be calibrated independently. The SRDL #1, calibrated with the Lower Circumpolar Deep Water method presented earlier (Fig. 2) has thus been used as the reference, allowing the determination of an offset for 6 other SRDLs.

For the three remaining SRDLs, the cross-comparison method was unable to provide a salinity offset because too few profiles were available on the Northern Kerguelen Plateau. They have thus been calibrated using direct comparison of deep T/S characteristics, leading to a somewhat lower accuracy (around 0.03) of the corrected salinity. Finally, the estimated offsets were found to range between -0.13 and 0.16, showing the importance of correcting the external field effect.

6. CONCLUSION

A validated seal dataset was produced with accuracies generally better than 0.02 °C in temperature and 0.03 in salinity. By presenting methods and results related to calibration and validation of SRDLs, this study aimed at providing a guideline for future deployments and calibration works. We hope that this work might be profitably used in a close future for a standardization of SRDL hydrography-related procedures.

7. REFERENCES

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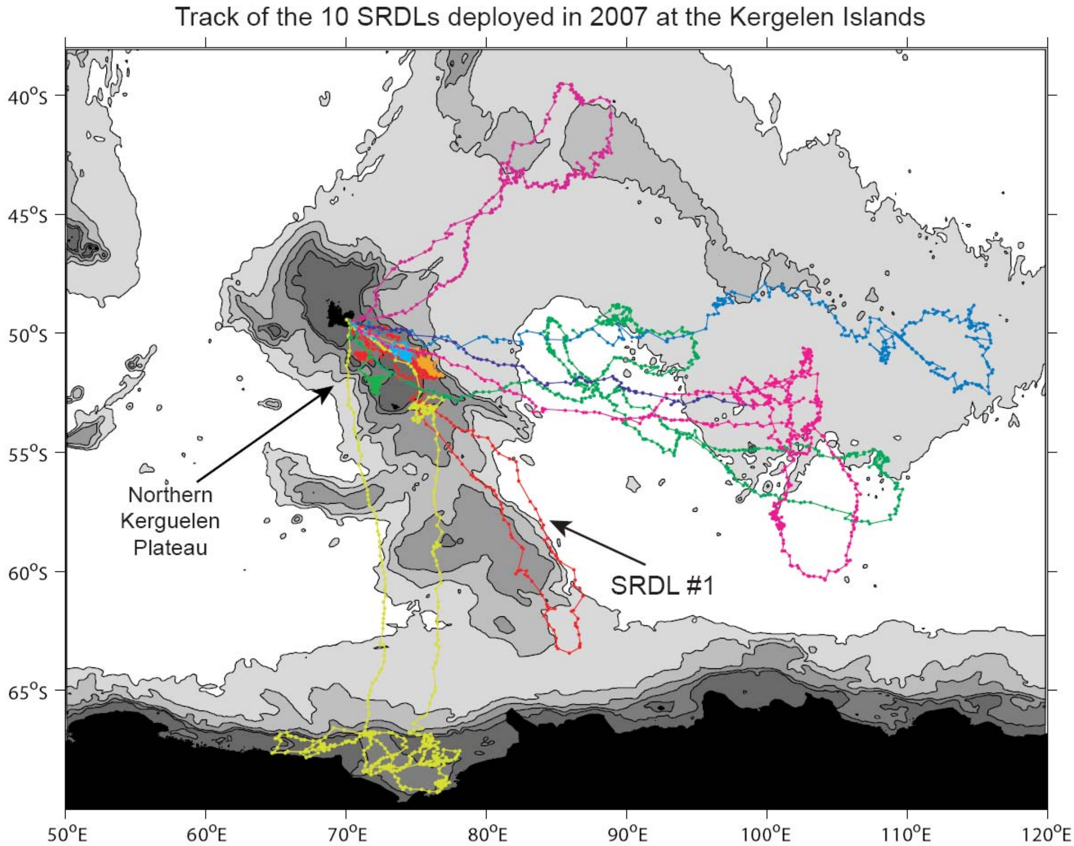

Figure 1: Spatial distribution of profiles collected by 10 SRDLs deployed in 2007 on the Kerguelen Islands.

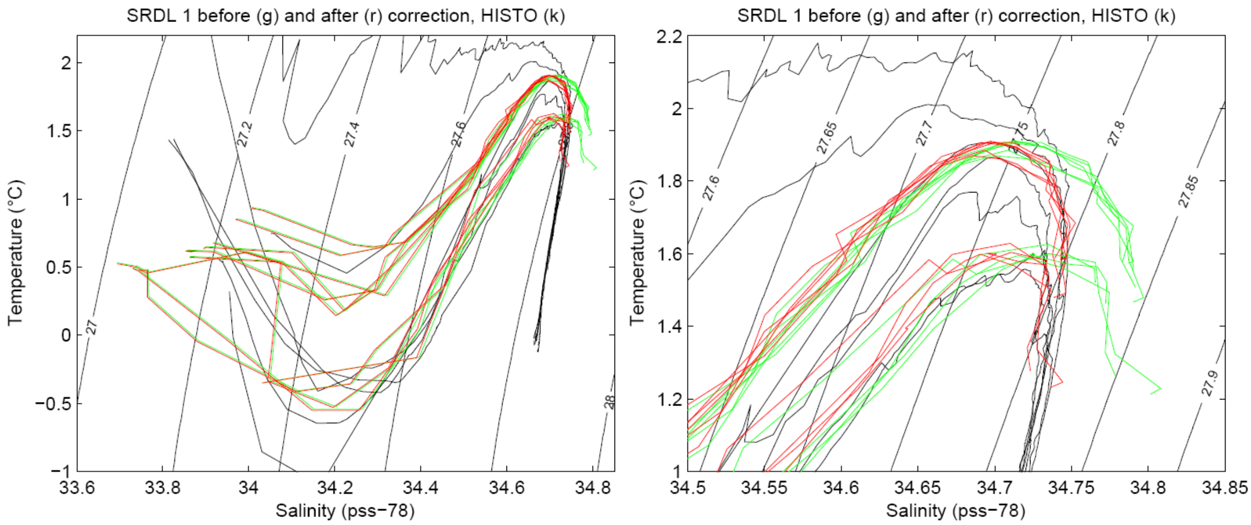

Figure 2: Visual validation of SRDL #1 profiles. Selected SRDL #1 profiles are presented with no correction (green) and after the pressure effect correction (red). Close historical profiles with comparable T/S properties are overlaid (black). Full T/S diagrams are shown in the right panel, while the deep part of these diagrams is shown zoomed in the left panel. The correction allows a much better overlapping with historical T/S diagrams at depth, as can be seen from the zoomed version of the figure (right part of T/S diagrams).