

# Activities of the calibration laboratory at HCMR-Crete – progress and challenges

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## Abstract

The calibration laboratory of HCMR-Crete has been developed to support the POSEIDON weather forecasting and monitoring system. It is set up to work with a range of sensors, which include temperature, conductivity, turbidity, Chl-*a* and oxygen. A large temperature-controlled tank with an approximate volume of 1.5 m<sup>3</sup> is used to achieve salinity and temperature gradients where necessary.

The calibration procedures followed are compliant with manufacturer recommendations; however, our main focus is on data ranges recorded in the eastern Mediterranean area. Processing and evaluation of calibration data focuses on minimising sensor drift by recalculating corrected coefficients at regular intervals. Special effort is made in order to establish a time-dependent filter that would perform dynamic data corrections following the sensor drift.

In the future we aim to utilise pre- and post- deployment calibration procedures to examine biofouling effects and define its contribution to the overall sensor drift. As sensors are expected to contribute to data assimilation as part of an integrated sampling system, we also focus on defining overall errors and their sources in order to improve sensor performance.

Although a large number of sensors are deployed every year in the European seas, calibration procedures vary significantly between laboratories. Thus it would be very constructive to work towards common practices, an approach already in place for observational platforms (buoys, ferryboxes, and gliders) and we believe a similar set-up along with a possible certification method would be very useful.

**Keywords:** operational oceanography, buoy network, calibration, biofouling

## 1. Introduction

The POSEIDON monitoring and forecasting system of the Eastern Mediterranean ([poseidon.hcmr.gr](http://poseidon.hcmr.gr)) uses a variety of platforms ranging from coastal buoys equipped with a few basic met-ocean sensors to open sea stations with an extensive list of sensors targeted to both physical and biochemical process and their coupling at various time scales (Petihakis *et al.*, 2010). Three multi-parametric deep water observatories currently

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operate: the E1-M3A mooring operating in the Cretan Sea since 2000, Athos station in North Aegean and Pylos mooring site that operates in the SE Ionian Sea. These stations host sensors for temperature and salinity at several depths ranging from surface to 1000 m as well as Chl-*a*, dissolved oxygen, PAR and light attenuation at 20, 50, 75 and 100 m (M3A). The surface buoy hosts a complete set of sensors for air-sea interaction studies (wind speed and direction, air pressure, air temperature, wave height and direction, relative humidity, precipitation, radiance, irradiance, radiometer and pyranometer) as well as an ADCP for current speed measurements in the upper 100 m. A total of 20 CTs and CTDs plus the surface sensors are always deployed in the field for a period of 6 up to 8 months before they are replaced. The large number of the deployed sensors and the need for high quality data led to developing of calibration methods and infrastructures to cover the needs of the POSEIDON monitoring and forecasting system.

## 2. Calibration strategy

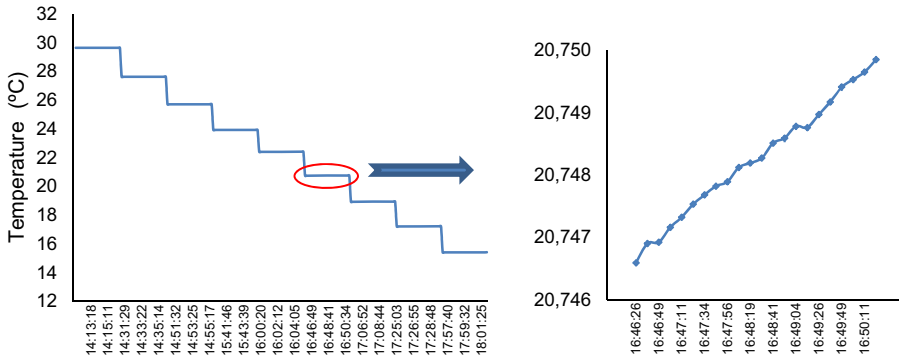
In order to minimise the calibration time and expenses, our calibration procedure is designed in such a way as to cover the range of the measured parameters present in Greek seas. For temperature this translates to a range of 11–28°C. Keeping that in mind and given the regional salinities (31–39.6 psu) as well as the min-max deployment depths we estimate a calibration range for the conductivity sensors between 3.5 and 6.47  $\text{Sm}^{-1}$ . For turbidity and Chl-*a* sensors the calibration procedure is carried out with reference solutions with low concentrations, which correspond to the actual values measured in the oligotrophic open seas around Greece. Dissolved oxygen sensors are calibrated over the range of 0–100% saturated solutions resulting in different concentrations depending on salinity and temperature. Furthermore in the future we are aiming to adjust even further the calibration range of each sensor to the specific local conditions at each deployment site.

## 3. Equipment

### 3.1 Infrastructures

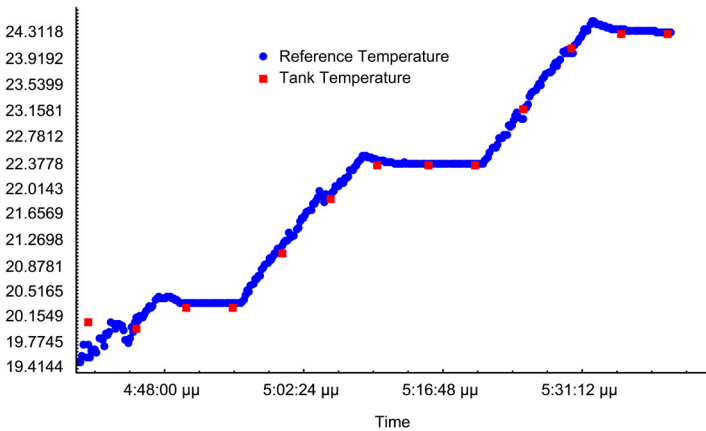
The calibration facilities at the HCMR Thalassocosmos complex in Crete include a fully equipped laboratory with a custom-made large calibration tank, two smaller plexiglass tanks and a number of reference sensors and all the necessary apparatus for temperature, salinity, Chl-*a*, turbidity and dissolved oxygen sensor calibration. The support team consists of the HCMR technicians and scientists, who prepare the instrumentation, perform field experiments, service and maintain the instruments and assist users during experiments in the calibration facility.

The T/C calibration tank has an inner diameter of about 122 cm and an inner height of 120cm, allowing an adequate number of sensors to be immersed in it. The tank walls are PVC with a polyurethane filling and are 9cm thick, providing the necessary heat insulation. It is equipped with a 2000 W heating element and an electric motor with a propeller for the efficient homogenisation of the tank water (Zervakis, 2008).



**Figure 1** Temperature calibration experiment a) full-range time steps; b) single time step temperature evolution.

The large volume of the T/C tank allows the simultaneous immersion of 4 CTD units (SBE 16 plus) inside the filtered seawater. The continuous stirring and the use of the CTD pumps effectively eliminate salinity spikes without causing any thermal errors, allowing discrete calibration steps (Figure 1a). The water sampling for the salinity analysis is performed from the same water level that the immersed instruments log data.



**Figure 2** The Haage bath performance in comparison with the SBE-35 Deep Ocean Standards Thermometer.

The two smaller 100 l plexiglass baths are equipped with a laboratory Haage temperature control circuit that permits fast temperature gradients and temperature stabilisation. The baths are used for smaller T/C sensors as well as DO sensors calibration and their stability is validated, during the experiments, by the SBE 35 Standards Thermometer (Figure 2).

### 3.2 Standards and references

The temperature reference sensor used in the HCMR calibration lab is the SBE 35 Deep Ocean Standards Thermometer manufactured by Seabird Electronics with an accuracy of  $0.001^{\circ}\text{C}$  and stability of  $0.001^{\circ}\text{C}$  per year ([www.seabird.com/products/spec\\_sheets/35data.htm](http://www.seabird.com/products/spec_sheets/35data.htm)). For salinity measurements we use an Autosal 8400A laboratory salinometer standardised with IAPSO Standard Seawater and an accuracy of 0.003 ppt ([www.guildline.com/oceanography.php](http://www.guildline.com/oceanography.php)).

An estimation of the calibration precision for temperature is  $0.0054^{\circ}\text{C}$  as a result of the square root of the sum of squares of the SBE 35 accuracy, the non-uniformity of the temperature distribution in the T/C tank and the tank stability during a calibration step. The non-uniformity of the temperature is considered to be the maximum difference between the reference sensor and a second temperature sensor calibrated by the manufacturer and its valued  $0.005^{\circ}\text{C}$ . This difference in temperature is recorded to the centre of the T/C tank where the sensors under calibration are placed. The stability of the tank is  $0.002^{\circ}\text{C}$  as the maximum difference in temperature recorded by the reference thermometer during a 2 minute calibration step (Figure 1b) (Inoue *et al.*, 2001).

Using the same approach the salinity uncertainly becomes 0.0062 psu as a product of the temperature error and the Autosal accuracy and without the contribution of sampling errors in this result.

For the calibration of the dissolved oxygen sensors the uncertainly lies on the accuracy of the Winkler titration and for the optical sensors measuring turbidity and Chl-*a* the uncertainly is a factor of the error in the production of the reference solutions in the lab.

## 4. Methodology

### 4.1 Procedures

The aim is to produce predefined calibration steps at regular intervals with an achieved homogeneity of the seawater mass inside the tank. During this multistep procedure the physical properties of the seawater are monitored and high frequency data and duplicate water samples are collected for later analysis with the high precision salinometer. The calibration of conductivity sensors is performed simultaneously with the temperature calibration and discrete gradients are created for each parameter. Seawater is collected one day prior to the calibration and the procedure begins with the highest temperature of the range selected using the tank-heating element. Using crushed (freshwater) ice, both parameters are gradually decreased to the lower point of the selected range. The procedure is fully controlled as shown in Figure 1a.

Dissolved oxygen sensors are calibrated in the Haage bath where through temperature changes we alter the oxygen concentration of the water covering the whole range of concentrations measured in the station. The turbidity and Chl-*a* sensors are calibrated against different reference solutions.

### 4.2 Data analysis

Generally the calibration data analysis involves defining the drift and trying to minimise it. In order to achieve that there are two approaches:

**Approach A:** Linear fit between reference values and sensor measurements (in most cases applied to the data).  $T_{ref} = aT_{sens} + b$

An example of temperature calibration results for 4 Seabird 16 plus CTD:

CTD s.n	a	b
5039	0.99975	+0.0015
5040	0.99977	- 0.0008
5052	0.99999	- 0.0029
5055	0.99961	+ 0.0025

**Approach B:** Recalculating the calibration coefficients of the sensor itself (applied to the sensor e.g. SBE CTs).

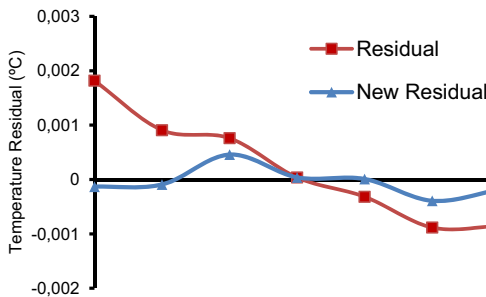
The second approach involves raw sensor data that permits the recalculation of the calibration coefficients of the sensor. Usually we can log the raw and the engineering units of the sensor but in some cases we need to convert engineering units to raw with a small price for accuracy because we are processing mean values. For the calculation of the SBE T/C sensor coefficients we have develop codes and routines that resolve the manufacture relations and fit the response of the sensor to the reference values. A linear least squares fit to the calibration constants will remove some of the random uncertainty associated with each calibration point, and the calibration history can show how a sensor is aging and if the latest calibration is consistent with the past calibrations.

An example is the Seabird temperature sensors. A thermistor is not a linear device; that is, the resistance of the thermistor is not linearly related to temperature. Thermistors behave in a logarithmic manner. Sea Bird has determined that the best fit to the calibration data for the their thermistor is of the form:

$$ITS-90 = \frac{1}{a_0 + a_1[\ln(f_0/f)] + a_2[\ln^2(f_0/f)] + a_3[\ln^3(f_0/f)]} - 273.15$$

Where  $f_0, f$  are the sensor frequencies and  $a_0, a_1, a_2, a_3$  are the sensor calibration coefficients.

This equation can be transformed to a linear third-order polynomial and a linear least squares fit allows the determination of the new calibration coefficients (Figure 3).

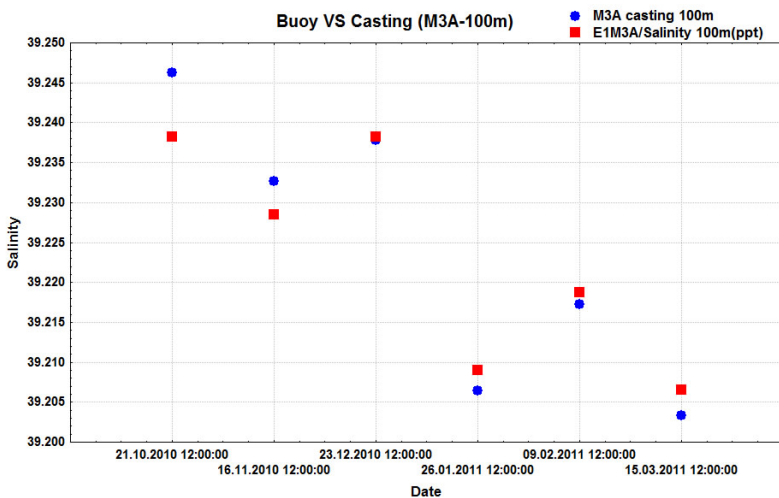


**Figure 3** Residuals of a SBE temperature sensor at each calibration point before and after the recalculation of new calibration coefficients.

## 5. Field validation

### 5.1 Survey data

Once the calibration procedure is completed a field validation is also performed prior to the deployment on the POSEIDON buoy network. This is a crucial step as errors can occur throughout the calibration procedure, thus avoiding long-term deployment (6–8 month period) errors. The performance of the calibrated instrument is checked against in-situ data and if necessary a correction coefficient is applied to the transmitted data. Especially at the M3A buoy we perform a monthly multi parameter survey that includes CTD casts, equipped with Chl-*a*, turbidity and dissolved oxygen sensors, plus water samples and zooplankton nets from various depths (Figure 4). The data correction for temperature and salinity is performed following the application notes published in the Seabird Electronics webpage ([www.seabird.com/application\\_notes/AN31.htm](http://www.seabird.com/application_notes/AN31.htm)). This approach computes an offset drift for temperature sensors based on pre- and post-deployment calibration data. Conductivity sensors usually drift by changing span (the slope of the calibration curve) so in this case the data correction involves the calculation of the slope from calibration and survey data.



**Figure 4** Monthly comparison of the conductivity sensor deployed at the M3A station in depth of 100m against the survey casting.

### 5.2 Biofouling

The SeaBird conductivity sensor (used on HCMR’s moorings and CTDs) uses a Beckman three-electrode conductivity cell as the variable resistance element in an AC Wien Bridge Oscillator. The measurement is contained entirely within the cell so the dimension of the cell is a critical factor. The drift of a conductivity sensor is generally due to electronic component aging, fouling that leads to dimensional changes in the cell geometry, and non-conducting material in the cell. Generally the electronic drift is smooth and smaller compared to the other factors (Saunders *et al.*, 2010). Biofouling is the major limiting factor in conductivity measurements (especially moored observations) in the ocean environment. In an attempt to “quantify” the biofouling contribution to the

sensor overall drift, experiments have been performed using the same CTD unit before and after the cleaning procedures recommended by the manufacturer (Medeot *et al.*, 2010). The results, in this case, indicate that drift due to biofouling is significantly higher than the electronic drift especially after long deployment periods (Figure 5).

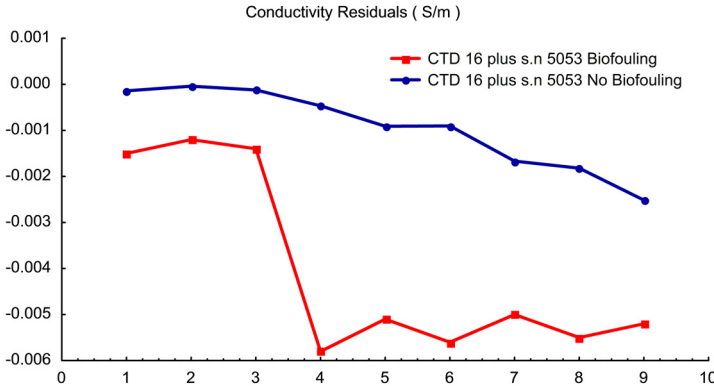


Figure 5 Residuals of a conductivity sensor before and after fouling removal.

### 6. Future perspectives

A major technical challenge for operational oceanography is to conduct high precision field measurements that produce high quality data available to the scientific community. In the case of extended scientific networks, such as EuroGOOS, the need for harmonisation of procedures and practises is an important issue that affects the overall quality of the produced knowledge. This statement stands out when it comes to calibration. Although several calibration laboratories operate all over Europe there are significant differences in methodologies and procedures as well as on infrastructures. In order to achieve the highest standards of performance for deployed sensors a closer collaboration and sharing of knowledge and practises will lead eventually to common adopted operation methods and significant cost reduction.

Future steps in our calibration activities involve both upgrade of equipment as well as improvement of existing methodologies, especially for optical and dissolved oxygen sensors. Thus by maintaining a detailed track of each sensor history in the field and through pre- and post- deployment calibration experiments and continuous surveys we will examine the contribution of biofouling, in terms of regional and seasonal parameters, to the overall drift. Furthermore due to different sensor technologies and demands we will further develop our analysis and fitting techniques in order to be able to minimise the drift as much as possible. The overall goal is a continuous procedure that will assure the maximum quality and will act as a dynamic filter to previous and future sensors measurements and data assimilations.

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