

A method to estimate the uncertainties and the representativeness of ship-based CTD profiles

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Introduction

- CTD profilers (Conductivity – Temperature – Depth): instruments used in oceanography to obtain temperature and salinity profiles during oceanographic surveys.
- Lowered to as much as 6.000 m using an electro-mechanical cable deployed from a ship at a fixed point.
- **Profiles are used as references** in ocean databases, to validate the profiles produced by other instruments such as the drifting floats in the Argo network, to feed numerical models, to estimate **ocean heat content**.
- Temperature sensor **highly stable**, calibrated to ± 2 mK to meet the recommendations of the WOCE (World Ocean Circulation Experiments) programme.
- However, little is known about their measurement errors when the instrument is lowered, and these are poorly quantified.
- Study based on a **dual-sensor set-up, numerical modelling** of the measured signal and an **assessment of the measurement uncertainties**.
- Evaluation of the uncertainties in the temperature profiles linked to the instrument, to the mixing during descent and ascent, and to the **natural variability of the environment**, by water level.
- This assessment led to the definition of what is known as the **representativeness** of profiles.

Representativeness = Instrumental uncertainty + Natural variability

The Instrumental uncertainties

Depends on the **depth positioning** p of temperature measurements ($u_c(p)$), and on:

- + calibration (u_c) and drift over time (u_d);
- + self-heating (u_{sh}) and **response time errors** (u_r);
- + pressure effect on the needle that shelter the thermistor (u_p);
- + temperature sensor linearity errors (u_l);
- + viscous heating (u_v).

$$u_c(T) = \sqrt{u_l^2 + \left(\frac{u_{sh}}{\sqrt{3}}\right)^2 + u_c^2 + u_v^2 + \left(\frac{u_d}{\sqrt{3}}\right)^2 + \left(\frac{u_p \times p}{\sqrt{3}}\right)^2 + (u_c(p) \times \text{grad}(T))^2 + u_r^2}$$

The numerical model of the response time errors.

- Depends on the temperature gradients of the medium.
- Depends on the sea state.
- Sea state ≤ 2 : linearization of the profile per segments.

$$T = (T_0 - T_{10} + \tau v) e^{-\frac{t}{\tau}} + vt + T_{10} - \tau v$$

- Sea state > 2 : linearization per segments and measurement of the boat oscillations.

$$T = \left(T_0 - T_{10} + \tau v + \frac{\tau \omega \Delta T_1}{1 + (\omega \tau)^2}\right) e^{-\frac{t}{\tau}} + vt + T_{10} - \tau v + \frac{\Delta T_1(t)}{\sqrt{1 + (\omega \tau)^2}} \sin(\omega t + \varphi)$$

With $\Delta T_1(t) = \text{grad}(T) \times \Delta p(t, \omega)$



	Distribution	Double profile
Repeatability	Triangular	0.14
Thermal sensitivity	Triangular	0.40
Drift (sn 766)	Rectangular	0.14
Hysteresis (sn 766)	t-distribution	0.02
Calibration	Gaussian	0.20
Pressure sensor standard combined uncertainty:		0.49



	pdf	At 0 bar (mK)	At 600 bar (mK)
Linearity	Gaussian	0.1	0.1
Self-heating	Rectangular	0.06	0.06
Calibration	Gaussian	1.00	1.00
Viscous heating	Gaussian	1.00	1.00
Drift over time	Rectangular	0.17	0.17
Pressure effect	Rectangular	0.00	2.90
Pressure positioning	Triangular	0.00	0.00
Response time	Gaussian	0.00	0.00
Temperature combined standard uncertainty:		1.43	3.22

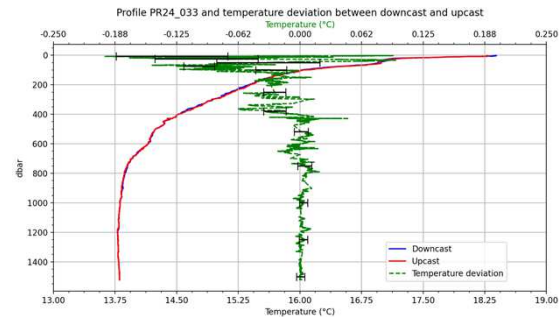
Implementation of the equations of the measured temperature

- Using of the Python package called Ruptures (<http://ctruong.perso.math.cnrs.fr/ruptures>)
- 29 breakpoints per descent and 29 per ascent corresponding to 60 gradients per profile.
- time between two detections filtrated to $24 \times 1/f$, where 24 is the sampling frequency of the CTD profiler.
- Threshold applied to eliminate the quick temperature variations during the detection: $1^\circ\text{C dbar}^{-1}$ for sea states ≤ 2 and $0.3^\circ\text{C dbar}^{-1}$ for sea states > 2 .
- ω extracted from the pressure signal at the time when the carousel is in standby at the maximal depth for a few minutes.
- Amplitude of oscillations to calculate $\Delta p(t, \omega)$: sliding window Fourier Transform applied to measure this amplitude along the descent and ascent profiles, giving a spectrogram.
- Taking account of the difference in height of the two temperature sensors according to the relationship:

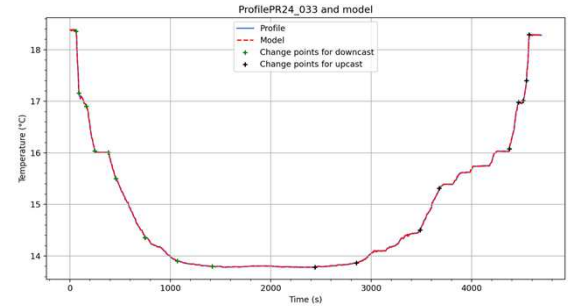
$$\delta T = T_{bottom}(p) - T_{top}(p - 1.4)$$

Results of the implementation

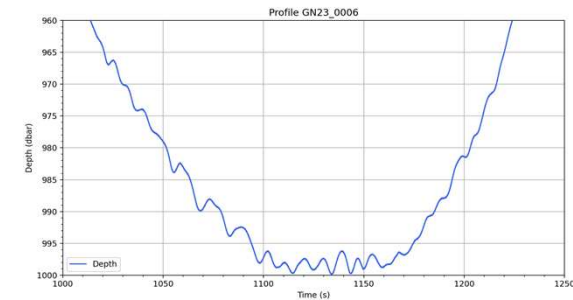
For most profiles, the natural variability is greater than the instrumental expanded uncertainty during the measurements periods.



Measured temperature during downcast and upcast + deviation signal obtained from the two temperature sensors + combined expanded uncertainty per water layer superimposed to the error signal (black bars).



Temperature profile as a function of time and result of the numerical modelling of this signal obtained with the equation.



Zoom of the pressure signal between the descent phase and the ascent phase to illustrate the oscillations due to the movement of the boat.

Conclusion

- Method applied to ARGO profiling floats.
- Results of four campaigns compiled in an Excel table to quantify the representativeness of data per water layers.
- Ultimate aim of the Excel table: to create a database that can be used to quantify the representativeness of CTD profiles carried out in areas close to the recorded profiles.
- Using of artificial intelligence, to associate values of instrumental uncertainty and natural variability by water level, with profiles obtained with a single pair of sensors (most of recorded profiles).

Reference:

Le Menn, M.; Dumas, F.; Calvez, B.; Assessment of the Representativeness and Uncertainties of CTD Temperature Profiles. *J. Mar. Sci. Eng.* **2025**, *13*, 213. <https://doi.org/10.3390/jmse13020213>

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