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An in-situ experiment identifying flow effects on temperature measurements using a pumped CTD in weakly stratified waters

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ABSTRACT

A simple experiment shows that the tubing leading to and from the pumped duct of temperature T and conductivity C-sensors of a Sea-Bird Electronics 911plus CTD can cause artificial T-effects as a function of the instrument package vertical velocity. This artifact is due to a pressure difference between inlet and exhaust tubes of the pump-system, even when they are mounted at precisely the same height (pressure level). The vertical velocity dependent pressure difference causes an estimated internal flow speed variation of $\pm 0.5\ \mathrm{m\ s^{-1}}$ inside the pumped duct that generates artificial temperature variations of ± 0.5 mK due to sensor frictional heating. First, this effect is demonstrated in weakly stratified waters by precise but horizontal mounting of the two tubes (at the same height), which leads to similar amplitudes of erroneous T and opposite sign as erroneous T observed using the standard vertical mounting. Secondly, the use of identical surface area tubes, mounted (at the same height) in the vertical downward direction, successfully removes the unwanted pressure gradient and hence the temperature dependence. This second mounting, acting as a hardware filter, can effectively replace a recently proposed software filter.

1. Introduction

Ship's and/or instrument's motions affect high-precision temperature (T) measurements using a shipborne Sea-Bird Electronics SBE911plus Conductivity-Temperature-Depth (CTD) profiler in very weakly stratified waters where the buoyancy frequency N is only a few cycles per day, cpd (van Haren, 2015; Uchida et al., 2015). Artificial temperature variations (ΔT) were found in data from deep Puerto Rico Trench (PRT) waters (van Haren, 2015), as well as, in retrospect, in historic data from deep NE-Atlantic waters (Fig. 1), to be correlated with the instrument package vertical velocity, under zero phase-lag, like,

$$\Delta T = \gamma_T dp/dt, \quad \gamma_T = -3 \pm 1 \times 10^{-4}\,{}^\circ\mathrm{C\,s\,dbar^{-1}}, \tag{1}$$

where p denotes pressure and t time. Here 'instrument package vertical velocity' refers to the vertical velocity of the instrument as it is lowered or hoisted. This velocity is modulated by the motion of the sheave over which the cable attaching the instrument package to the ship lays, that motion being induced by the action of surface gravity waves on the ship. Conductivity was not correlated with the instrument package vertical velocity.

Following (1), at about $1\ \mathrm{m\ s^{-1}}$ downcast velocity, average T was cooler by about $6 \times 10^{-4}\ {}^\circ$C compared with that of upcast data. The data underlying the empirical relation (1) were measured using a standard vertical mounting of the pumped TC-duct with tubing of different inner diameters (ID's) as per instructions from the manufacturer (Sea-Bird, 2012). Uchida et al. (2015) reported data obtained by using a standard horizontal mounting of the pumped TC-duct were not affected by such instrument velocities.

Although the cause of the erroneous T-data was not found, the relation (1) suggested unwanted flow-induced pressure variations across the pumped TC-duct. It could not be attributed to the dragging of warmer/cooler waters by the CTD-frame, as this would give erroneous T in variable phase difference with pressure (Trump, 1983), but not strictly in phase with pressure tendency (first derivative of pressure with respect to time) as in (1). To remedy this artifact, a software post-processing low-pass filter was proposed (van Haren, 2015) to remove the variations due to surface wave effects. Naturally, this filter could not remedy the 'constant' difference between down- and upcast or any other mechanical variation in instrument package vertical velocity varying at intervals of 20 s or more.

In this note, a simple in-situ experiment is described to determine the cause of the artificial T-variations and to create a hardware solution for the problem outlined in (1), that is, to minimize the value of γ_T, for a vertically mounted SBE911plus CTD. As the T-measurement is partially dependent on flow speed

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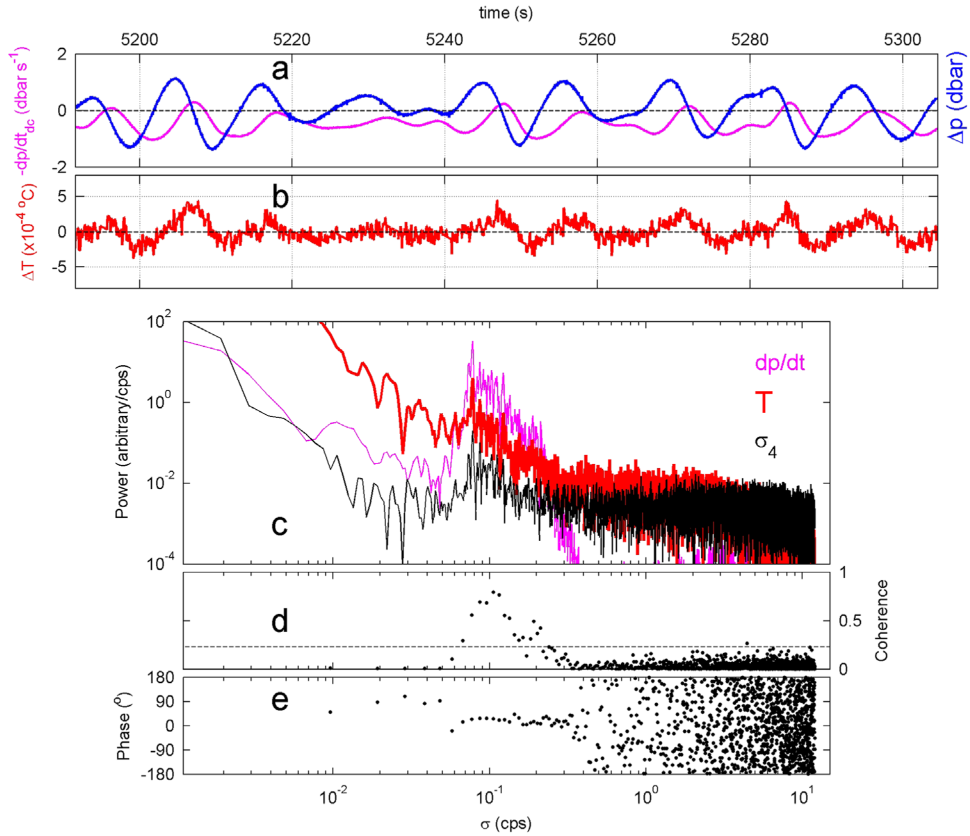

Fig. 1. Nearly raw 24 Hz sampled historic downcast data obtained from the R/V Pelagia using a standard vertical CTD-configuration at 37° 30′N, 12° 34′W in 5100 m water depth on 29 October 2012. Short example time series for the 50-m depth range [4785,4835] m. (a) Detrended pressure (blue) and its (negative signed) first time derivative −dp/dt, 2-dbar-smoothed (purple). (b) Detrended temperature. (c) Nearly unsmoothed (~3 degrees of freedom; dof) spectra of data from the 4000–5000 m depth range. (d) Moderately smoothed (40 dof) coherence between dp/dt and T from panel c., with dashed line indicating the 95% significance level. (e) Corresponding phase difference. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

through sensor frictional heating, our experiment is set-up to verify the hypothesis that the 'internal' flow speed inside the TC-duct is not constant. We presume this is caused by a variable pressure tendency across the duct induced by the turbulent flow around different ID's of intake and exhaust. The null hypothesis is then a constant (pump) flow yielding no variation in internal flow speed despite any variations in instrument package vertical velocity. We speculate that the hypothesized variation of the internal flow speed as a function of the instrument package vertical velocity is reduced to zero when identical ID's are used for end-tubing of intake and exhaust. Ideally, such a solution would work for all instrument package vertical velocity variations.

2. Data

We had brief opportunity to make experimental observations from the Dutch R/V Pelagia above a NE-Atlantic abyssal plain off Portugal. Using freshly calibrated T-C sensors (calibration date: April 2015), SBE911plus CTD-profiles were obtained at 36° 56′N, 12° 58′W in 5100 m water depth on 17 August 2015. The sensor housings were mounted vertically next to the main electronics housing (Fig. 2) in a frame which can be used independently, or inside a 1.5 m high Rosette-carousel holding 24 water sampling bottles. For the present experiment the CTD-frame was lowered, without Rosette-carousel, via a heave compensator. This compensator reduces the effects of the ship's vertical motions by no more than 50% from the surface to 2000 m depth. Below 2000 m, the heave compensator does not function because of the weight of the cable and instrument package.

The standard CTD configuration has T- and C-sensors vertically mounted in a 'TC-duct' attached to a 3000 rpm pump, realizing an internal flow speed of 2.3 m s^{-1} near the sensors, just behind the intake. The sensors are near the bottom of the electronics frame, with an unobstructed flow exposure when moving downward. The exhaust of the pumped duct is at the same (pressure) level as the intake, so as to in principle eliminate the ram effect of dynamic pressure to maintain a constant flow passing the sensors (Sea-Bird, 2012).

However, the cross-section area of the downcast directed inlet and exhaust perpendicular to the mean down- and upward velocity direction is not identical in the standard configuration. This is, as per instructions from the manufacturer (Figs. 1-2 in Sea-Bird, 2012), because no tube is used over the inlet of the TC-duct and a soft long tube is used over the pump outlet to bring the exhaust down to the same height as the inlet. The intake has a 0.004 m ID while the exhaust 0.012 m. This gives a one order of magnitude difference between intake and exhaust internal speeds for a given flow-rate. In addition, a more complex pressure and flow difference is expected between the different tubes of intake and exhaust, because of the strongly turbulent character of the flow. We modify the end-tubing of both inlet and exhaust for the present in-situ experiments.

Due to time limitations, we could not make a cast with standard CTD-configuration. As a reference we use an R/V Pelagia standard CTD-cast obtained in the same deep-sea basin 60 km NNE of the above position in 2012. When these historic data were taken, the surface wave heights were half of those when PRT observations were made reported in van Haren (2015) and about two-thirds of those when the present observations were made.