

RBR

Performance of two RBR*concerto* CTDs on OSNAP mooring CF-06

April 2019

1 Summary

Two RBR*concerto* CTDs were deployed for two years on an OSNAP mooring in the East Irminger Sea in the North Atlantic. The RBR CTDs were mounted in parallel to SBE instruments to facilitate a direct comparison between the measurements. One RBR instrument, installed at nominal depth 1500 m, flooded after 10 days, the second, installed at nominal depth 250 m, collected data for 15 months (13 months after the deployment) until the batteries failed.

A direct assessment of temperature and salinity from the CTDs moored at 250 m over the 1 year period was not straightforward because the RBR and SBE sensors were moored at slightly different depths, and the depth of the sensors varied substantially during the mooring period because of mooring line tilt (248 to 826 dbar). The depth variations caused the relative depth difference between the sensors to vary from 1 to 8 dbar. A comparison of temperature and salinity between the RBR*concerto* and SBE37 CTDs moored at 250 m revealed differences within the instrument accuracy specifications, with no evidence of sensor drift or near-field interference by the mooring cable on conductivity. Power spectra of the temperature and salinity from both instruments illustrates the high frequency information captured by the RBR's high sampling rate ($\Delta t = 30$ seconds) relative to the SBE's low sampling rate ($\Delta t = 15$ minutes).

2 Introduction

The Overturning in the Subpolar North Atlantic Program (OSNAP), a collaborative international program, is an effort to determine the strength of the meridional overturning circulation and associated heat and freshwater fluxes in the subpolar North Atlantic. Within this program, 15 oceanographic moorings were deployed during cruise 07 leg 6 (AR07-02) of the R/V Neil Armstrong in late-summer 2016 and recovered during cruise 30 leg 6 (AR30-06) of the same R/V in late-summer/early-fall 2018.

When Clark Richards was at RBR, he provided two RBR*concerto* CTDs for testing on a two year OSNAP mooring deployment. The instruments were RBR *concerto* CTDs built for R&D purposes, serial numbers #60373 and #60349. They were paired with SBE37 Microcats on mooring CF-06 on Greenland's southeast shelf break (59°57.42'N; 41°44.58'W, bottom depth 1831 m) and deployed during OSNAP cruise AR07-02 and recovered September 16, 2018.

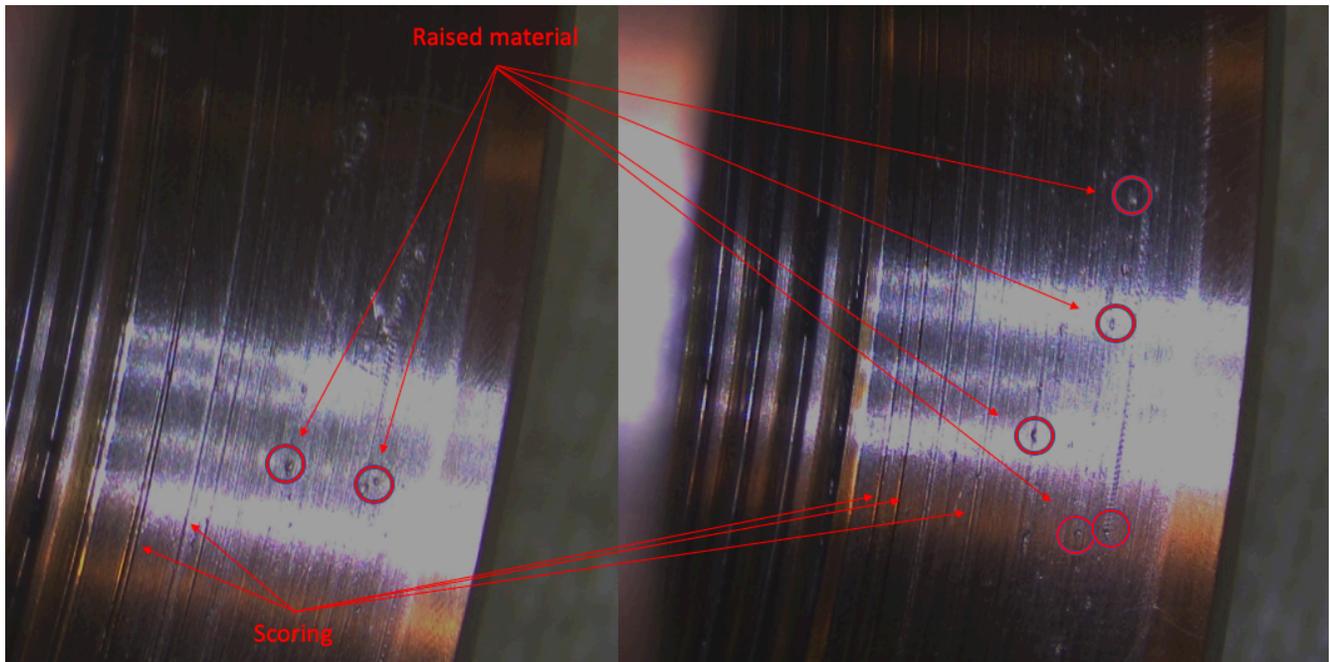
Both instruments were equipped with the cylindrical "mooring" conductivity cell. RBR*concerto* #60349 had a plastic pressure case, and was moored at 250 m. RBR*concerto* #60373 had a titanium pressure case, and was moored at 1500 m. Both instruments were configured to sample at 30 s intervals for the two year deployment.

In this report, we summarize the electrical and mechanical performance of each CTD, and we then evaluate the measurement performance of each CTD relative to their "companion" SBE37 CTDs. Note that the RBR and SBE data as plotted have not been adjusted for offsets and drift such as might be found by a post-deployment calibration.

3 Electrical and mechanical instrument performance

3.1 RBR*concerto* #60373 / 1500 m

The data from this instrument indicate that it stopped recording 11 days after the deployment. The instrument was inspected at RBR, and it was clear from the inspection that the instrument flooded. The titanium housing had damage on the O-ring surface of the sensor end cap. This can be caused by the threads of the sensor end cap coming in contact with the body. See photos below:



These units were built for R&D purposes, and they were not assembled following the standard RBR production procedures and quality checks. We recently implemented a better workflow for R&D units that go out for deployment. Note that standard commercial CTDs are assembled by production staff with cleaned and greased O-rings, and a fresh calibration/pressure test without any disassembly/reassembly afterward.

3.2 RBR*concerto* #60349 / 250 m

The instrument was set to sample at 30 s intervals for two years; however, the behaviour near the end of the dataset indicates that the batteries died after 15 total months of sampling (13 months in the water).

The rsk file contains a series of reset events near the end of the time series. The reset events (error-4 & error-10) are due to the logger not having sufficient power to take a sample. The logger will continue to try and sample, and if it cannot it will reset (error-4) and repeat until the power is too low - at which point the power will shut down entirely, and the clock is reset (error-10). The logger will power up the CPU and restart logging if the voltage from the batteries recovers. During the period between resets, long gaps of data are present. That is because the data logger caches in RAM a certain amount of samples before writing them to the internal flash memory. Hence, every time the data logger resets, the samples available in RAM but not yet written to the internal flash memory are lost.

These error events are written to the memory, and due to the method in which they are stored, they can cause the read time to be extended, resulting in a much longer than expected download time.

Furthermore, the data timestamps are not accurate for the sections of data populated by many reset events. When an error-10 occurs the clock is reset, however, Ruskin will assign a new date and time to the next data point that is 12:00 am on the following day so that it keeps the dataset in the correct order.

There is no clear indication as to why the batteries did not last for the entire two-year deployment. The post-deployment assessment of the instrument did not highlight any electrical fault that would have caused the cells to prematurely die. The sampling and sleep current of the unit are within the expected range, which would suggest that the batteries were not fresh when the unit was deployed, either due to the logger being sent with used batteries or the instrument was turned on before deployment. When RBR calibrates or configures a unit for shipping the sampling rate is set to 1Hz, and at that rate, 50% of the battery capacity could be consumed in ~15 days. It may have been that the unit was enabled before shipping, as it was not handled by our production team, where they use a specialized "Configure for shipment" button that sets the configuration and deployment schedule and disables logging. When this button is pressed it updates our records with the pdf template of the configuration, giving us a history of how the unit left our facility. This unit did not have this report generated before shipping, reinforcing our decision to have all instruments (whether for a customer or a research and development project) to go through the final test process handled by production.

4 Measurement performance

4.1 RBR*concerto* #60373 / 1500 m

RBR*concerto* #60373 was paired with SBE37 #5922. As mentioned earlier, this Concerto flooded after about 10 days of operation. The first signs of malfunction were evident in conductivity on the 5th day of operation (August 23, 2016), when a bias in salinity measurements (about -0.02 psu) appeared (Figure 1). Five days later, on August 28th, 2016, the logger stopped recording.

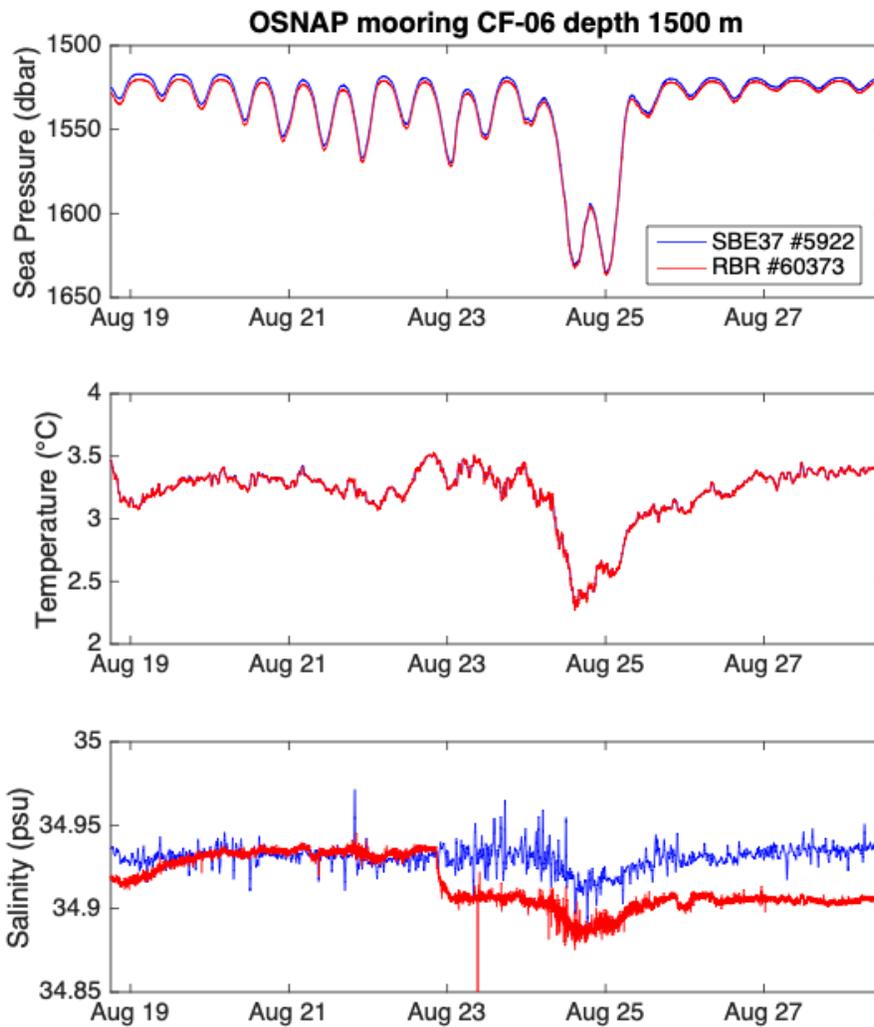


Figure 1. Measurements collected by RBR*concerto* #60373 during a 10-day period before it flooded.

4.2 RBR*concerto* #60349 / 250 m

RBR*concerto* CTD #60349 was paired with SBE37 #3589. It collected data for a total of 15 months, 13 of which were in the water (August 18, 2016–September 16, 2017) (Figure 2). Although the instrument was set to sample at 30 s intervals for two years, it stopped logging prematurely because the batteries died. The Ruskin battery life calculator predicts that an RBR*concerto* CTD should run for more than 4 years when a single sample is taken every 30 s.

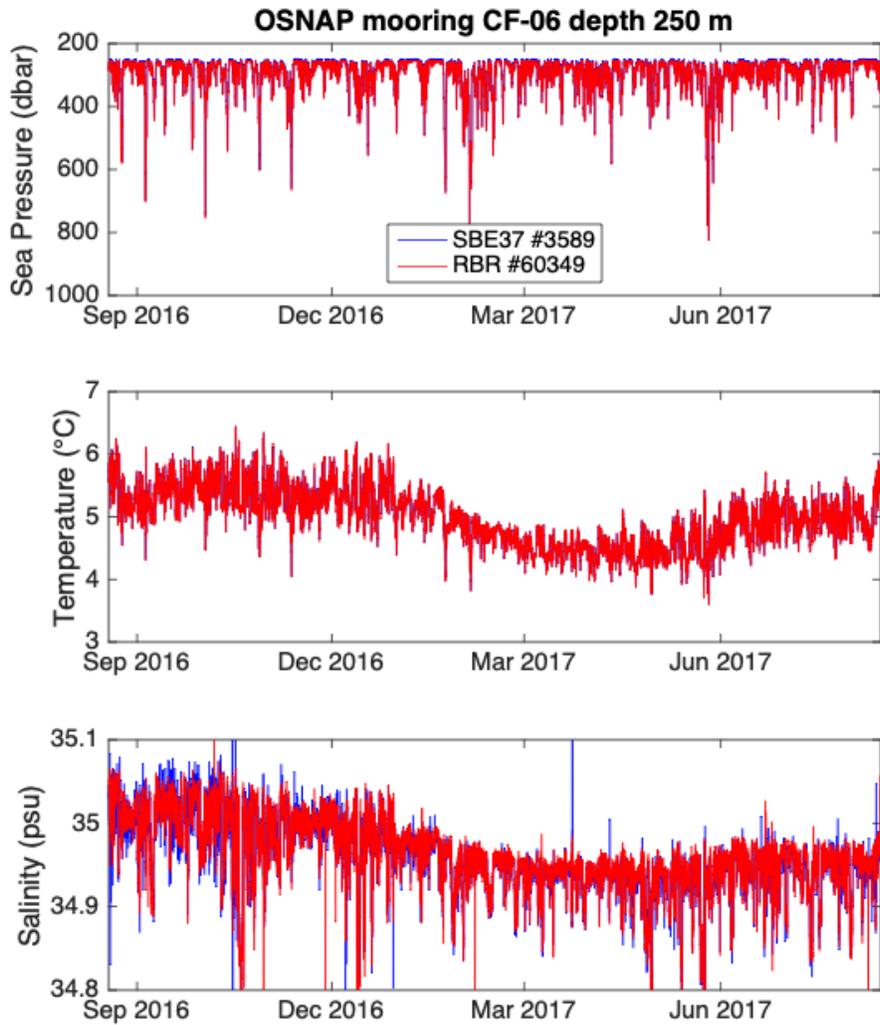


Figure 2. Measurements collected by RBR*concerto* #60349 during the 12 month period before batteries began to fail.

Toward the battery end of life (the final 30 days starting August 15, 2017) several reset events happened (Figure 3), meaning data were not collected during periods of hours to days. These gaps occur because the RBR data logger caches in RAM a certain number of samples before actually writing them to its internal flash memory. Hence, every time the data logger resets, the samples available in RAM but not yet written to the internal flash memory are lost.

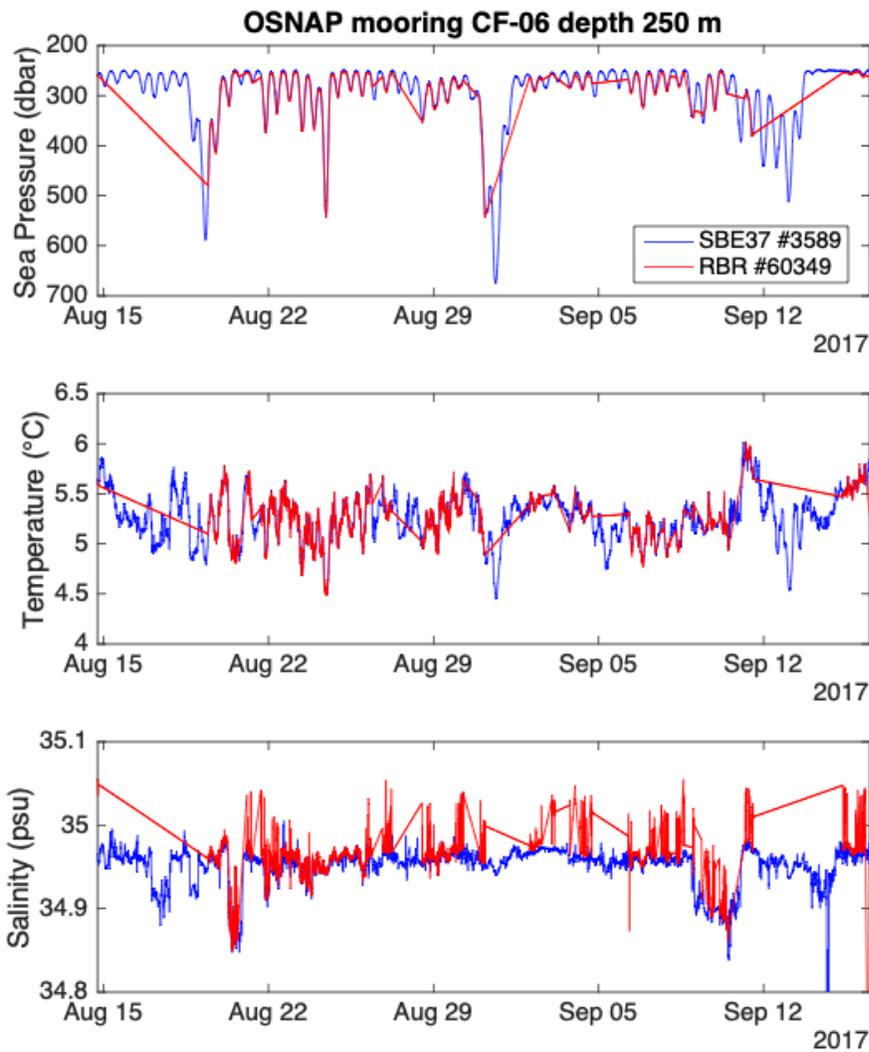


Figure 3. Measurements collected by RBR instrument #60349 during the 30-day period before batteries died. Straight lines indicate the periods between reset events when the collected data were lost.

Gap-free RBR data were collected during a 361-day period, from August 18, 2016 to August 15, 2017. In order to directly compare the RBR to the SBE, their data had to be placed on common timestamps. A lagged correlation analysis of the pressure records revealed that the timestamps were offset by 60 s. After correcting for the time offset, the data were interpolated on to a common time grid.

Basic statistics were computed on the difference between instruments (RBR - SBE) in the following variables: sea pressure, temperature, conductivity, and salinity (Table 1).

Table 1. The differences between the measurements by RBR #60349 and SBE37 #3589 averaged over the period August 18, 2016 to August 15, 2017.

	Mean	S.D.	minimum	maximum
Sea Pressure (dbar)	3.77	0.27	0.99	8.22
Temperature (°C)	-0.0052	0.0269	-0.4736	0.5872
Conductivity (mS/cm)	-0.00075	0.0263	-0.9783	0.5503
Salinity (psu)	0.0026	0.0073	-1.0782	0.2248

The averaged differences in conductivity, temperature, and salinity met the accuracy specification for each instrument. The temperature difference (-0.0052°C) was at the limit of the specifications considering both instruments have an uncertainty of 0.002°C. The difference in conductivity was -0.00075 mS/cm, which is much smaller than the specifications for either instrument.

Assuming both pressure sensors are error free indicates that the RBR*concerto* was mounted a few meters below the SBE37 on the mooring line. In stratified waters this means that the measured differences in water temperature and salinity could be due in part to the relative position of the instruments in the water column. The sign of the errors in temperature and salinity supports this conclusion although without a profile for reference this cannot be proven.

The difference between the depths of both instruments demonstrated semidiurnal tidal cycles (Figure 4), which indicates the mooring was "blown over" by strong tidal currents. Looking at the pressure records independently shows that the sensors were displaced vertically by over 500 m. The pressure difference between the RBR and SBE varied between 0.99 and 8.22 dbar.

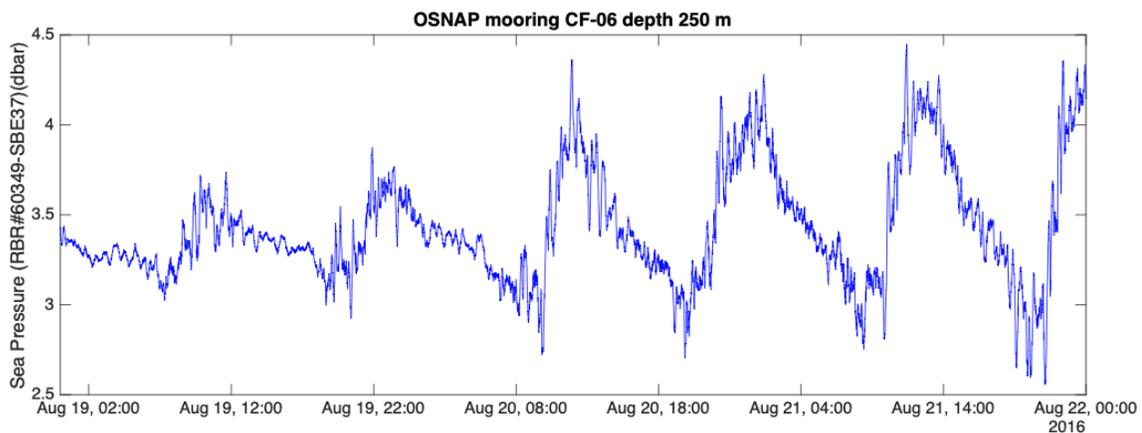


Figure 4. An example (3-day period) of the difference between pressure measured by RBR #60349 and SBE37 #3589, demonstrating a semidiurnal tidal cycle.

The differences between the RBR and SBE measurements of temperature and conductivity/salinity may have been caused by the vertical variation of the water properties rather than an inherent bias between the sensors. As such, analyzing the difference between sensors for secular trends (e.g., gradual sensor fouling) may not be instructive. Instead, we calculated linear trends in sea pressure, temperature and salinity for both instruments independently, and then analyze the slopes for statistical significance (Tables 2-3) using the Student's Z-test [$Z = (b_{RBR} - b_{SBE}) / \sqrt{SE_{b-RBR}^2 + SE_{b-SBE}^2}$]. When calculating standard errors (*SE*) of all parameters, the effective number of observations (degrees of

freedom) for both instruments was reduced using a 'decorrelation length scale' factor estimated from the autocorrelation functions of RBR and SBE measurements. For the SBE37 #3589, the decorrelation scale was set to 10, for RBR #60349, the decorrelation scale was 300 (1.5 hours for both instruments).

Table 2. Linear regressions (trends) in sea pressure, temperature and salinity measured independently by RBR #60349 and SBE37 #3589. The shaded table cells indicates intercepts and slopes significantly different from zero.

	RBR #60349				
	Intercept		Slope (day⁻¹)		
	Estimate	S.E.	Estimate	S.E.	p
Sea Pressure (dbar)	298.35	1.99	-4.46·10 ⁻³	9.60·10 ⁻³	0.299
Temperature (°C)	5.39	0.0127	-2.26·10 ⁻³	6.10·10 ⁻⁵	0.000
Salinity (psu)	35.002	0.0012	-2.27·10 ⁻⁴	5.56·10 ⁻⁶	0.000
	SBE37 #3589				
	Intercept		Slope (day⁻¹)		
	Estimate	S.E.	Estimate	S.E.	p
Sea Pressure (dbar)	294.7	1.99	-5.03·10 ⁻³	9.50·10 ⁻³	0.320
Temperature (°C)	5.40	0.0128	-2.27·10 ⁻³	6.15·10 ⁻⁵	0.000
Salinity (psu)	35.001	0.0012	-2.33·10 ⁻⁴	5.69·10 ⁻⁶	0.000

The sea pressure of each instrument did not change significantly during the 1-year analysis period. At the same time, both RBR and SBE instruments detected significant decrease in temperature ($2.26 \cdot 10^{-3} - 2.27 \cdot 10^{-3} \text{ } ^\circ\text{C} \cdot \text{day}^{-1}$) and salinity ($2.27 \cdot 10^{-4} - 2.33 \cdot 10^{-4} \text{ } \text{psu} \cdot \text{day}^{-1}$). The trends in both temperature and salinity were likely due to natural variability in the water properties (i.e., an annual cycle that didn't quite return to its starting value) rather than sensor drift. The differences between each pair of slopes were insignificant (Table 3).

Table 3. The differences between the slopes of linear regressions of Sea Pressure, Temperature and Salinity measured independently by RBR #60349 and SBE37 #3589.

	RBR #60349		SBE37 #3589		Z	p
	Estimate	S.E.	Estimate	S.E.		
Sea Pressure (dbar)	$-4.46 \cdot 10^{-3}$	$9.60 \cdot 10^{-3}$	$-5.03 \cdot 10^{-3}$	$9.50 \cdot 10^{-3}$	0.042	0.483
Temperature (°C)	$-2.26 \cdot 10^{-3}$	$6.10 \cdot 10^{-5}$	$-2.27 \cdot 10^{-3}$	$6.15 \cdot 10^{-5}$	0.157	0.438
Salinity (psu)	$-2.27 \cdot 10^{-4}$	$5.56 \cdot 10^{-6}$	$-2.33 \cdot 10^{-4}$	$5.69 \cdot 10^{-6}$	0.745	0.228

5 The advantage of sampling at high frequency

Spectral power densities of pressure, conductivity, temperature, and salinity, were computed using the Welch's modified periodogram method (Figure 5) (Welch, 1967).

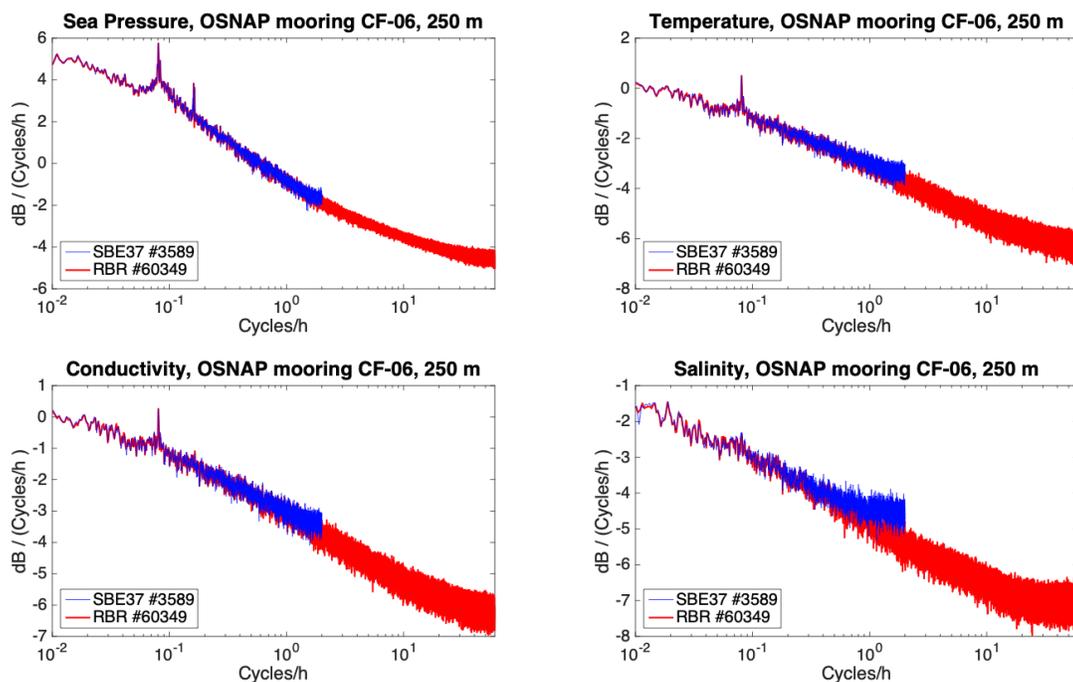


Figure 5. Power spectra of Sea Pressure, Conductivity, Temperature, and Salinity calculated using Welch (1967) method using RBR #60349 and SBE37 #3589 observations at nominal 250 m mooring depth.

The spectra reveal the typical geophysical red spectrum with diurnal and semidiurnal tidal lines. The spectra are similar at frequencies ranging from annual to hourly. The SBE spectra appear to flatten at higher frequencies although the shape of the spectra at higher frequencies is not clear given the 15 min sample spacing. The spectra from the RBR data continue to decrease with increasing frequency at a consistent slope until about 10 - 30 cycles per hour, and at higher frequencies the spectra flatten.

6 References

Welch, P. D. (1967), "The use of Fast Fourier Transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms" (PDF), IEEE Transactions on Audio and Electroacoustics, AU-15 (2): 70-73, doi:10.1109/TAU.1967.1161901