Assessment of RBRcoda T.ODO performance on long-term deployment and profiling in Bedford Basin

1 Executive summary

The RBR*coda* T.ODO is an optical dissolved oxygen (DO) sensor with a standard accuracy of 8 µmol/l and a power consumption of only 36 mJ/sample. It is available in three variants, T.ODO|slow (30 s τ), T.ODO|standard (8 s τ), and T.ODO|fast (1 s τ), providing oceanographers more options for applications, such as long-term deployments, vertical profiling, and integration on gliders. To assess the performance of the RBR*coda* T.ODO on long-term mooring and profiling applications, field tests were conducted in Bedford Basin (Halifax, Canada) from September 2018 to December 2018. The measurements were compared to measurements collected using a Sea-Bird Scientific CTD with SBE43 dissolved oxygen sensor and to water bottle samples collected from a rosette. The results indicate that RBR*coda* T.ODO is stable and accurate over a 4-month mooring deployment and for profiling application.

2 Why Bedford Basin?

Bedford Basin's oxygen level is highly variable throughout the year, making it a perfect natural testing site for oxygen sensors. An estuary located in Halifax, Nova Scotia, Canada, the basin has a maximum depth of 71 m and connects to Halifax Harbour by a narrow and shallow sill. The oxygen level in the basin is modulated by both stratification and plankton blooms, and it exhibits strong seasonal variations. The deepest point of the basin, known as Compass Buoy Station (44° 41' 37" N, 63° 38' 25" W), has oxygen concentrations varying from near saturation to near zero throughout the year, with occasional spikes associated with upper water intrusions.

The Bedford Basin Monitoring Program (Department of Fisheries and Oceans, Canada) collects weekly measurements in the basin that can be used to validate the RBR*coda* T.ODO data. The program collects temperature, salinity, and DO profiles with an SBE25 CTD and an SBE43 DO sensor. It also collects water bottle samples near the surface (~5 m) and near the bottom (~60 m) which are processed for DO concentration using the Winkler method. The water bottle samples provide excellent reference data to compare against the RBR and SBE sensor readings.

3 Instruments and deployments

Three RBR*coda* T.ODO sensors were selected for testing: T.ODO|slow #93074, T.ODO|standard #93029 and T.ODO|fast #93150.

3.1 Moored deployment

The RBR*coda* T.ODO|slow #93074 (referred to below as T.ODO) and a SBE37 CTD were deployed on a floating pod to ~60 m depth at the Compass Buoy Station, from September 2018 to December 2018 (Figure 1). Both the T.ODO and SBE CTD were configured to sample at 1 Hz for the first minute of every hour. The SBE CTD on the floating pod measured temperature at the same time to compare with temperature measured by the T.ODO.

For the DO comparison, the T.ODO data selected were those closest in time to when the SBE DO and bottle DO weekly profile data were collected. The SBE DO and bottle DO profile data were taken from the depth of the moored T.ODO (~60 m). The T.ODO data was averaged over 120 samples (60 seconds before and 60 seconds after the profiling) in time to compare with the weekly CTD DO and bottle DO profile data.

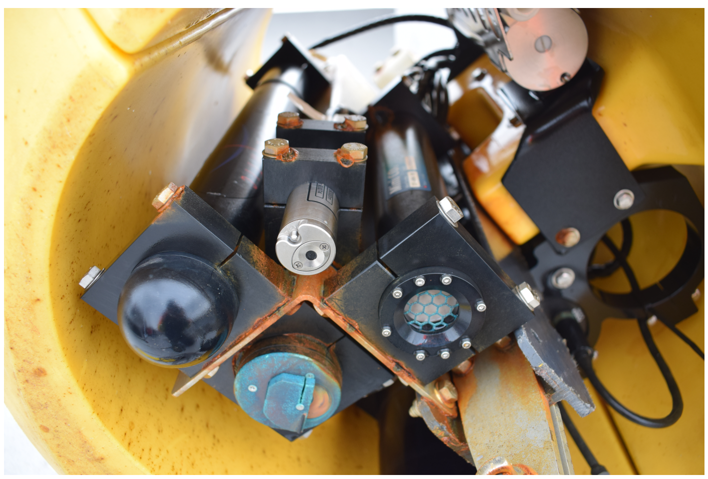

Fig. 1 RBRcoda T.ODO mounted beside SBE sensors on a floating pod for a long-term (4-month) mooring.

3.2 Profiling deployment

During a weekly Bedford Basin Monitoring Program cruise, an RBR*coda* T.ODO|standard (8s time constant) #93029 and RBR*coda* T.ODO|fast (1s time constant) #93150 were tested for use in vertical profiling. Both T.ODOs were connected to an RBR*concerto* CTD #66015, and the CTD was mounted beside the frame containing the SBE25 (Figure 2). The CTDs were profiled on Oct 24, 2018, from the R/V *Sigma T*. Dissolved oxygen profile data from both T.ODO|standard and T.ODO|fast sensors were compared to SBE DO sensor and water bottle DO data.

Fig. 2 RBRconcerto and two RBRcoda T.ODOs mounted on SBE cage with clamps for vertical profiling.

4 Data post-processing

The SBE43 DO data went through a post-calibration where the data were adjusted against winkler titration data.

4.1 Long-term mooring

The RBR*coda* T.ODO's temperature and dissolved oxygen outputs from the long-term mooring were evaluated.

The temperature data from the T.ODO and SBE CTD on the mooring pod were smoothed using a window length of 60 samples.

To facilitate the comparison between the moored observations and the profiles, we averaged T.ODO data over 120 samples which are closest in time to when the bottle samples were collected. For instance, if the profiling of bottles occurred at 12:40pm, the samples from T.ODO at 12:00 – 12:01pm (60 samples in 60 seconds) and 13:00 – 13:01pm (another 60 samples) were averaged. We also selected SBE data that were collected at the same time and depth that bottle samples were collected.

4.2 Vertical profiling

Post-processing on RBR data includes:

1. Smoothing the 6 Hz conductivity, temperature, and pressure data with a window length of 5 samples
2. Removing loops from ship heave
3. Deriving salinity
4. Bin averaging into 1 dbar bins

Post-processing on SBE data includes:

1. Tau and hysteresis correcting of DO data using default recommended values.
2. Low pass filtering with time constant of 0.1 s for temperature and conductivity, 0.5 s for pressure
3. Loop editing
4. Deriving salinity

5. Bin averaging into 1 dbar bins

Note that the SBE post-processing involves one extra processing step for tau and hysteresis correction of DO data. For RBR data, we will demonstrate a recently developed time response correction algorithm that has been implemented in RSKtools, RBR's open-source Matlab toolbox for data processing and visualization.

5 Results

5.1 Long-term mooring

The T.ODO|slow and SBE CTD long-term temperature measurements are consistent, with an average difference of 0.004°C. This difference is within the sum of the calibration specifications of ±0.002°C for both instruments. The DO measurements from T.ODO are generally lower than the bottle measurements, with an average difference of -0.36 mL/L (Figure 3). Both the RBR and SBE DO values are lower than the bottle DO except during the short mixing period, in November. The average difference between T.ODO and SBE43 is -0.19 mL/L, which is within the sum of the accuracy specifications of both instruments (T.ODO ±0.18 ml/L and SBE43 ±0.11 ml/L).

Note that T.ODO reported negative values when the DO concentration approached zero, near the end of October. This was due to errors in the calibration procedures (errors in Winkler titration at zero DO concentration); the problem has been corrected in the RBR calibration procedures.

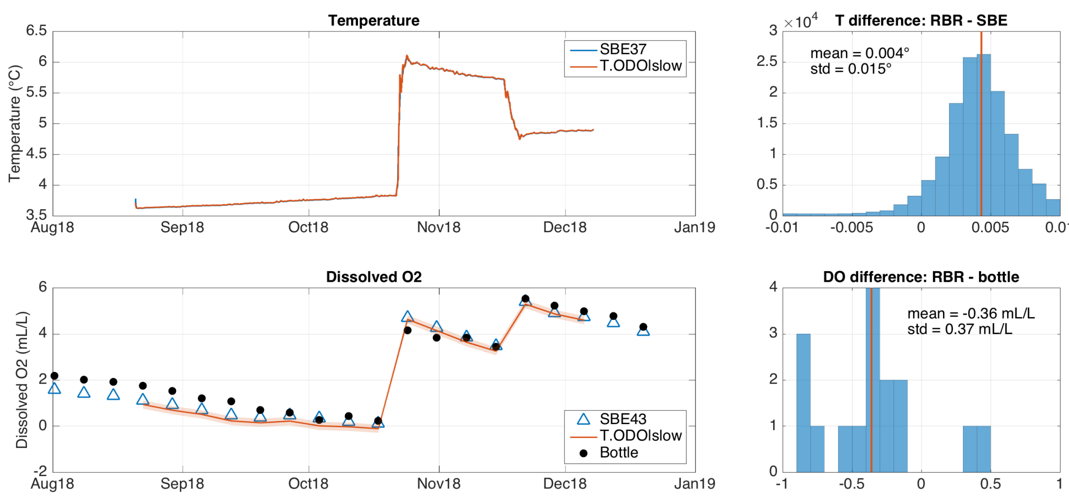

Fig. 3 Long-term (4-month) mooring: Temperature and DO measurements from RBRcoda T.ODO|slow, SBE and bottle (left 2 panels), histograms of the temperature differences between T.ODO and SBE (top right panel) and DO differences between T.ODO and bottle (bottom right panel)

Analysis of results:

The DO difference was smaller from November to December than from September to October. It is likely that a mixing event occurred in early November that brought water with saturated DO down to the bottom of the basin, and as such the DO spatial variation decreased. Mixing became less intense and the stratification dominated again after early December. Part of the difference between T.ODO and bottle DO data may be caused by a difference between the depth of bottle sampling and the depth of the mooring pod. Also, the bottle data is integrated over the height of the Niskin bottle, and the rosette introduces local mixing when it is lowered into position. By comparison, the DO from the T.ODO is confined to a relatively small volume near the optical window. Any vertical stratification could mean differences in DO measurements.

5.2 Vertical profiling

After post-processing, profiles from the RBR T.ODO|standard, RBR T.ODO|fast, SBE43, and bottle Winkler titrations were graphed against sea pressure. Profiles of the difference between both T.ODOs and the SBE DO were also plotted, as well as histograms of the differences (Figure 4). Due to the scarcity of bottle samples, the T.ODO measurements were not compared to the bottle samples.

The T.ODO|fast #93150 measured an oxygen concentration that varied closely with the SBE43 DO concentration, with an average difference of -0.05 mL/L and a standard deviation of 0.10 mL/L. The difference is small considering the accuracy specifications for the T.ODO and the SBE43 are ±0.18 ml/L and ±0.11 ml/L, respectively.

The average difference between the T.ODO|standard #93029 and the SBE43 is -0.08 mL/L and the standard deviation of the difference is 0.61 mL/L. The large standard deviation of the difference between this pair of sensors is caused by the ~8s time constant of the T.ODO. This has two effects. First, the measured signal from the T.ODO|standard lags the signal from sensors with shorter time constants. Second, high-frequency variations are damped to a greater extent in the T.ODO|standard. However, we will show that the T.ODO|standard measurements can be “sharpened” with a time response correction algorithm to both correct the measurement lag and recover some of the high frequency variability.

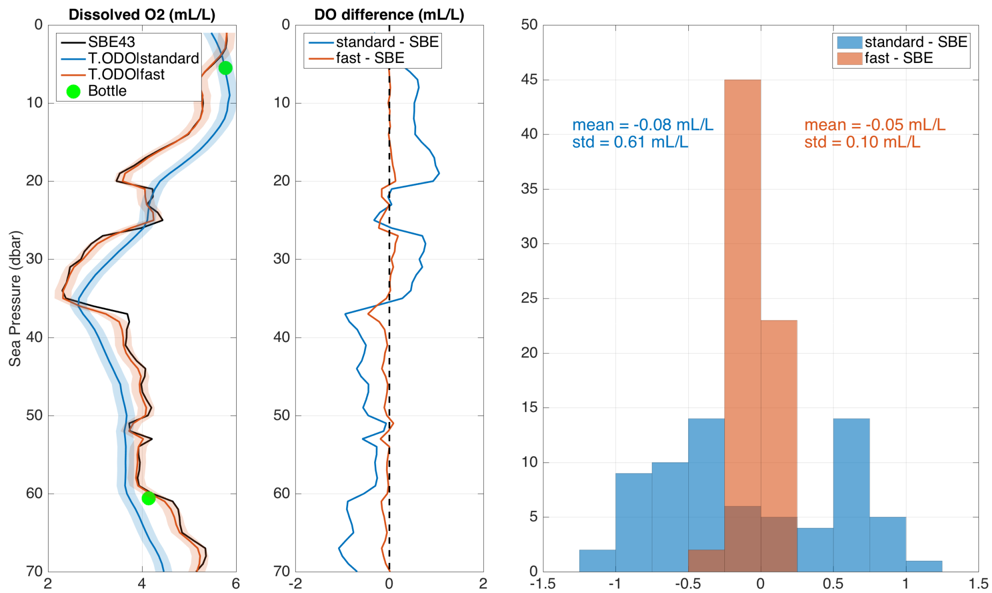

Fig. 4 Vertical profiling: DO from SBE, T.ODO|standard, T.ODO|fast and bottles (left panel), DO differences between T.ODO and SBE (middle panel) and histogram of the differences (right panel).

To meaningfully compare the T.ODO|standard with the T.ODO|fast, the T.ODO|standard response needs to be sharpened algorithmically (Sea-Bird calls this the "tau correction"). A recursive time domain algorithm was chosen for our application based on the assumption that the optode can be characterized by single pole response (e.g., Fozdar et al., 1985). The time constant for the algorithm was set to 8 s, and the smoothing time scale was set to 0 s. All sharpening algorithms amplify high frequency noise, in the original signal, therefore the sharpened data was smoothed with a 7-sample (~ 1 s) centred running mean.

The differences between the T.ODO|standard and the T.ODO|fast, and the sharpened T.ODO|standard and the T.ODO|fast, were computed and then plotted as profiles and histograms in Figure 5. The results show that the profile-averaged difference is still very small, changing from -0.03 to -0.09 mL/L, and the profile standard deviation decreased from 0.54

to 0.30 mL/L compared to the uncorrected data. More importantly, the measurement lag introduced by the T.ODO|standard has been corrected.

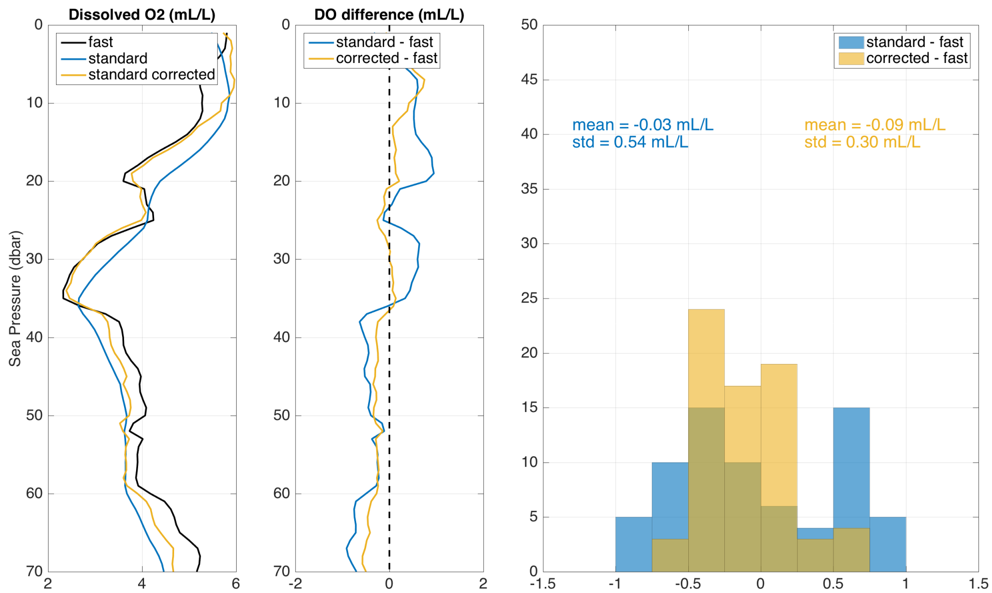

Fig. 5 DO from T.ODO|fast, T.ODO|standard and T.ODO|standard after time response correction (left panel), DO differences between T.ODO|standard with and without correction and T.ODO|fast (middle panel) and histogram of the differences (right panel).

6 Conclusions

The long-term mooring test conducted in Bedford Basin, Nova Scotia, Canada, from September 2018 to December 2018 demonstrated that the T.ODO|slow #93074 captures both temperature and dissolved oxygen variability with slightly underestimated DO compared to bottle samples. The underestimation may be partly due to temporal and spatial variations in DO.

The vertical profiles showed that the T.ODO|fast #93150 readings match the SBE43 readings closely, with profile-averaged differences of -0.05 mL/L. The T.ODO|standard #93029 outputs delayed signals relative to the T.ODO|fast when profiling, as expected. After application of the Fozdar et al. (1985) sharpening algorithm, the corrected signal has a much smaller standard deviation difference and the measurement lag was improved when compared with the T.ODO|fast.

To summarize, the RBR*coda* T.ODO|slow and RBR*coda* T.ODO|fast sensors are competent in long-term mooring and profiling applications, respectively. T.ODO|slow shows great stability when comparing to SBE43 weekly DO measurements. T.ODO|fast exhibits high accuracy that the differences with SBE DO samples are within the sum of the initial accuracies of both instruments. T.ODO|standard measurements in vertical profiling can be improved significantly with the use of the time response correction algorithm implemented in RBR's free and open-source Matlab toolbox: RSKtools.

7 Acknowledge

RBR appreciates the collaboration and support provided by our partners to accomplish this research project. We would like to express our very great appreciation to the Coastal Environmental Observation Technology and Research (CEOTR) group based at Dalhousie University and specifically Richard Davis, Madison Evans, Darrell Adams and Anna Haverstock, who provided RBR*coda* T.ODO integration support as well as carefully deployed and recovered the instrumentation for the long-term mooring experiment. We are particularly grateful for the help given by Clark Richards, Kevin Pauley, and Andrew Cogswell from Bedford Institution of Oceanography who planned and coordinated the cruise on *Sigma T*, and kindly provided reference data and documentations for data validation for both the mooring and profiling section. We'd also like to thank captain and crew of the Canadian Coast Guard Ship *Sigma T* and Winkler test technician Peter Thamer.

8 References

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9 Appendix

Specifications of RBR*coda* T.ODO and SBE43.

Unit/Instrument	RBR*coda* T.ODO	SBE43
Saturation (%)	±5%*	±2%*
Concentration (μM)	±8 μM*	±5.07 μM**
Concentration (mL/L)	±0.18 mL/L	±0.11 mL/L

*Parameters from manufacturers data sheet.
**Derived values using Garcia and Gordon (1992) under condition with 15°C temperature and 35 PSU salinity.