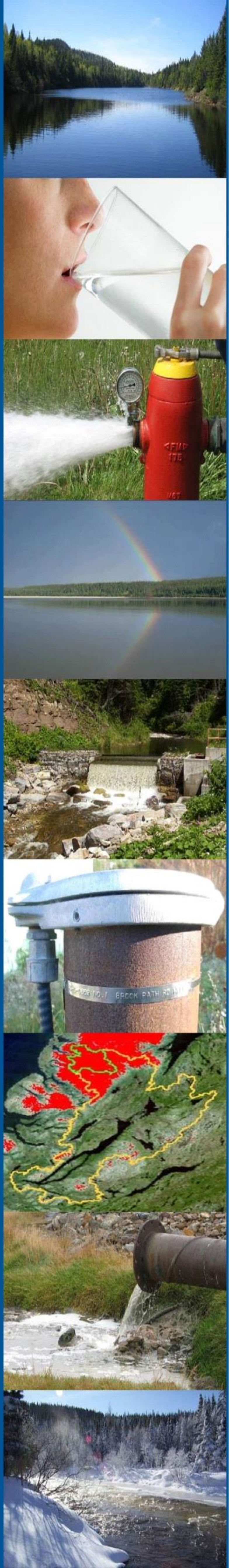

Comparison of Multi-Parameter Instruments:

YSI 6600, YSI Exo2, and Hydrolab HL4

2016-07-29

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Introduction


Figure 1: Paddy's Pond Station

The Real-Time Water Quality Monitoring (RTWQ) program within the Department of Environment and Climate Change specializes in remote retrieval of current conditions in selected water bodies across the province. This program relies heavily on specialized multi-parameter instrumentation capable of measuring, amongst other things, water temperature, pH, electrical conductivity, dissolved oxygen, and turbidity on a continuous basis. This field of technology is advancing with many makes and models available that could satisfy the needs of the RTWQ program.

Becoming familiar with the latest technology available in water quality monitoring is vital to the success of the RTWQ program. Since the inception of the RTWQ program, the Hydrolab DS5X has been used extensively; going forward there is an obvious benefit in comparing new equipment and methods to older, established equipment and methods. One such benefit is the ability to recommend and support the various types of equipment industry partners may choose to undertake mandated water quality monitoring requirements. This report examines three such alternatives and attempts to make some generalizations and comparisons between each.

To achieve this goal, three instruments were deployed at the Paddy's Pond station on the outskirts of St. John's and located near the outlet of the water body. Paddy's Pond station is accessed via Fowler's Road, off the CBS Bypass. The location makes the station an ideal testbed for new technologies. Since the YSI 6600 was already setup to send data to the Satlink II logger and transmit via GOES, the other sondes were setup to log data internally and were deployed alongside the YSI 6600 sonde on the rocky bed of Paddy's Pond.

In June 2014, the Paddy's Pond RTWQ station was converted from a Hydrolab DS5X to a YSI 6600 multisonde. Later in the year the Water Resources Management Division (WRMD) was loaned a Hydrolab HL4 multisonde from Campbell Scientific Canada Corp. allowing us to perform a comparison of the 6600, the HL4, and the YSI Exo2 also in our inventory. In the investigation, the aim was to compare not only the data produced by the three sondes, but also the operational challenges related to each model.

Procedure

Each sonde was treated as similarly as possible while following instrument-specific calibration requirements. All three sondes were set to record data internally on a 30 minute basis. Sondes were recovered every thirty days for a cleaning and calibration before being redeployed. The three sondes were deployed in stainless steel casings and tied together using stainless steel aircraft cable for safety.

The deployment period for each of the instruments is shown in Table 1.

Table 1: Sonde Deployment Intervals

Sonde	Deployment Start	Deployment End
YSI 6600V2	August 14, 2014	December 10, 2014
YSI Exo2	October 17, 2014	December 10, 2015
Hydrolab HL4	August 14, 2014	December 10, 2015
Concurrent Period	October 17, 2014	December 10, 2015

Operational Comparisons

YSI – 6600

Figure 2: YSI 6600 V2

In the past, this model had been used by WRMD mainly as a spot-sampling instrument during grab sampling programs and special projects. It has had limited use within the RTWQ monitoring program at the Waterford River station since April 2014 and some limited deployment at Paddy's Pond since June 2014.

Compared to the Exo2 and HL4 sondes, the 6600 is not overly user-friendly upon first use. The text-based user interface (UI) when used with a computer or YSI 650 handheld unit is unfamiliar to many users who are more comfortable using a graphical user interface (GUI).

Calibration of the 6600 is straight-forward once the user is familiar with the UI and the procedure for each sensor, which differs somewhat from the calibration for the standard DS5X in the RTWQ program.

The 6600 has presented some challenges to its incorporation into the RTWQ program. A common issue encountered is the production of negative turbidity values in clear water. It has been explained that this can be the result of improper calibration technique. However, even after altering technique and following the process outlined in the manual, negative turbidity values have continued to be an issue on occasion.

Another characteristic of this model that has been frustrating is the inability to alter the output of parameters via SDI-12 protocol – the standard communication protocol within the RTWQ data collection platforms (DCP). A small and inadvertent addition of a parameter to the 6600's SDI-12 output could impact all the data recorded at the station. This quirk makes it challenging to switch a RTWQ station to a 6600 unless the user is comfortable with programming the DCPs datalogger.

YSI – Exo2

The successor to the 6600 model is the Exo, which comes in two forms: the smaller 2" diameter Exo and the larger 4" Exo2. The Exo has been fully designed from the ground up to fix many of the shortcomings of its predecessors. The instrument boasts, amongst other features, "smart sensors", waterproof connectors, and a concentration on metadata. The RTWQ program currently owns four EXO2s with additional instruments owned by industry partners but maintained by the RTWQ program. The Exo sondes can be connected to a computer or handheld computer using a cable or Bluetooth connection (non-functional while underwater).

Figure 3: YSI Exo2

Calibration of the Exo2 sonde is similar to the 6600 in many ways. Interestingly, however, the smart sensor feature provides an opportunity to streamline and simplify the calibration of multiple Exos. Because the calibration is stored onboard the sensor (as opposed to the sonde itself in older models), multiple sensors of the same type can be affixed to a single sonde and calibrated simultaneously – saving time and calibration standard.

Not without its own challenges, the custom-designed GUI is intended to make the instrument simple to operate. However, the GUI can be confusing due to the use of unintuitive pictographs and menu structure.

The unusually short lifespan of the pH sensor tips caught RTWQ staff off guard as experience has shown that the tip can last less than 6 months, in some cases. While the tip is less costly than replacement sensors on other models, the frequency of replacement negates this by far.

Hydrolab – HL4

It is a major redesign of the body components, internal circuitry, and GUI. The HL4 highlights semi-automated calibration and, like the Exo, the importance of metadata. The HL4 is reminiscent of the DS5 in many ways, especially the sensors. Because of this shared heritage, the HL4 calibration process is very familiar to RTWQ staff.

Figure 4: Hydrolab HL4

Currently, the HL4 is only available in a smaller form factor – 2" diameter – with a larger version to be released in the future. The small form factor restricts the number of sensors that can be simultaneously deployed. The HL4 sonde used in this investigation did not possess a turbidity sensor unlike the 6600 and Exo2.

The sonde WRMD received was an early pre-release version possessing some unexpected software bugs that made its use challenging from time to time. Additionally, at one point, the pH sensor ceased the production of data and was no longer available to calibrate. After discussions with the manufacturer, it may have been due to a loose connector.

Data Comparisons

The following are comparisons of parameters for the YSI 6600, YSI Exo2, and Hydrolab HL4. Grab samples are represented as black triangles on pH, specific conductivity, and turbidity graphs.

Water Temperature

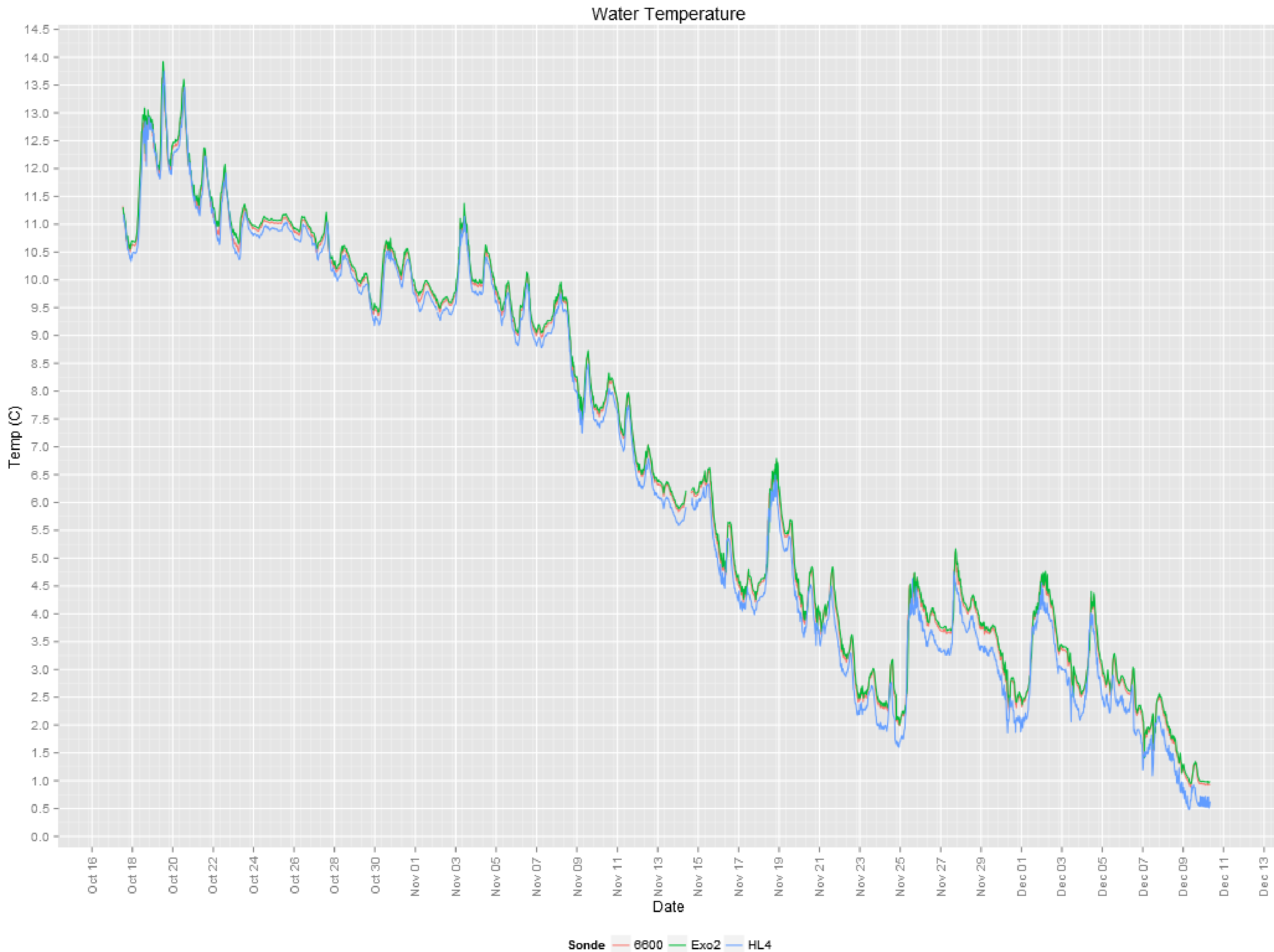


Figure 5: Water temperature from YSI 6600, YSI Exo2, and Hydrolab HL4

Environmental temperature is often measured using a thermocouple wherein the surrounding temperature alters the resistance in an electric circuit. Based on the changes in resistance of the circuit, temperature can be determined. This technology is well-understood and is relatively simple in its application. As a result, all three sondes show little deviation from one another compared to other parameters.

The YSI 6600 and Exo2 sondes were especially similar with the Hydrolab HL4 tending to report slightly lower values.

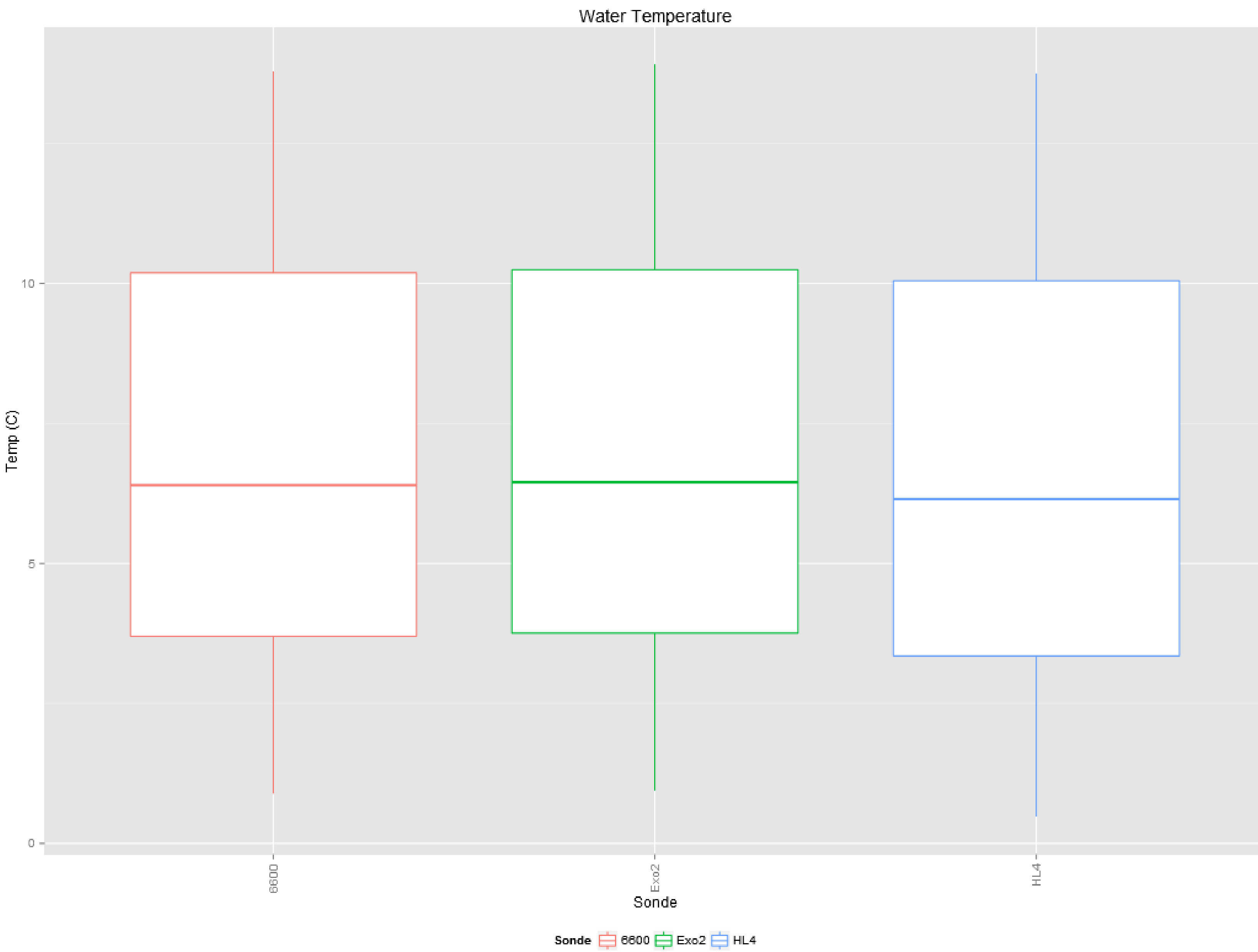


Figure 6: Boxplots of water temperature from YSI 6600, YSI Exo2, and Hydrolab HL4

As seen in Figure 1, water temperature was similar across all three sondes. This is clearly reflected in Figure 2 where there is almost total overlap of boxplots between each sonde.

pH

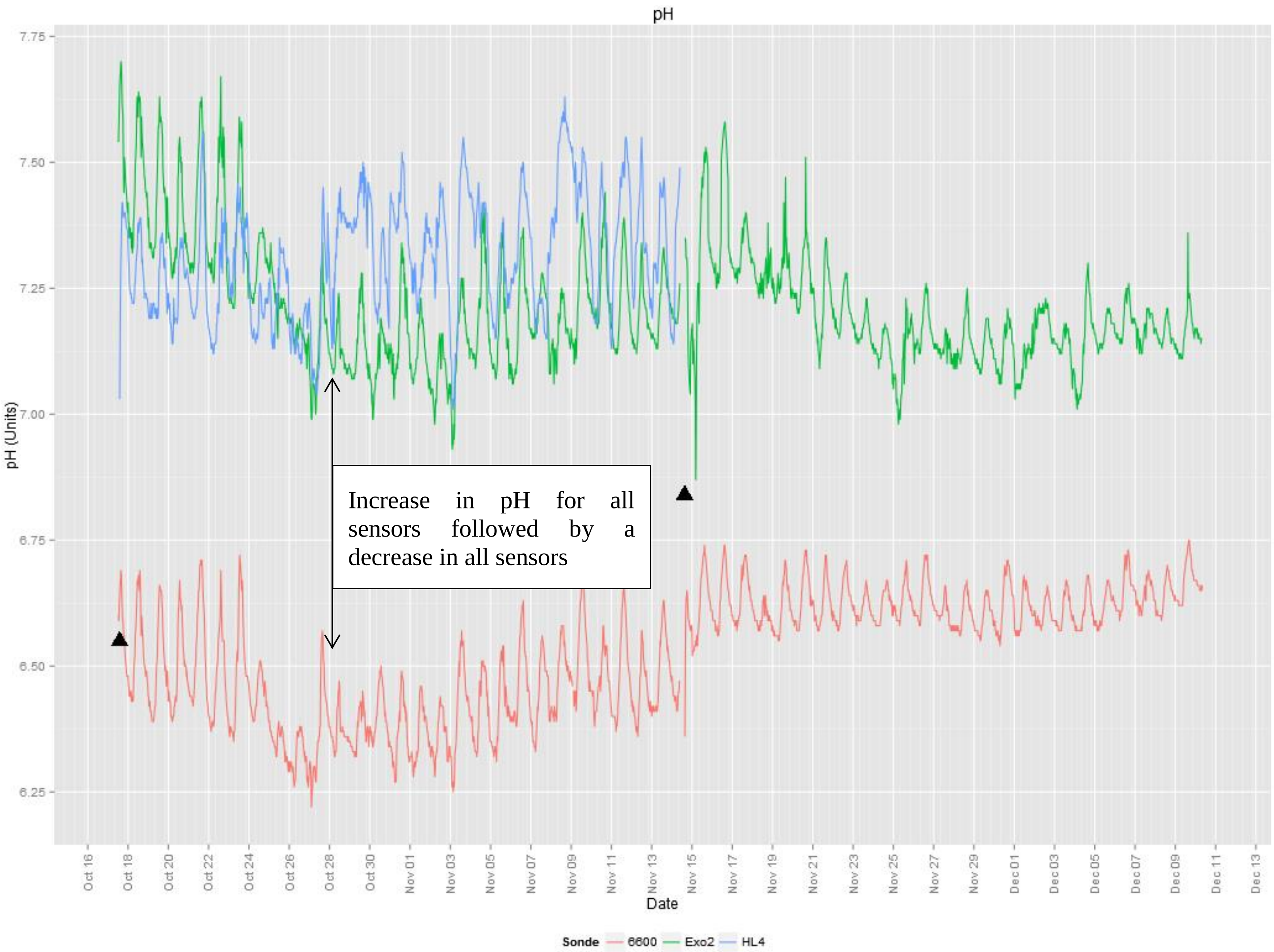


Figure 7: pH from YSI 6600, YSI Exo2, and Hydrolab HL4

Comparison of pH between each of the three sondes shows a variety of interesting features. The YSI 6600 pH data tends to fall closer to the two available grab samples while the Exo2 and HL4 tend to report substantially higher values.

The 6600 and Exo2 pH variations appear similar in magnitude and slope while the HL4 pH variation is nonlinear in that increases in pH seem to be unexpectedly large and subsequent decreases are smaller (see inset for example).

A major impediment to the comparison of pH values across all instruments is the uncertainty regarding the age of the 6600's pH sensor. The differences observed could be largely related to that one variable.

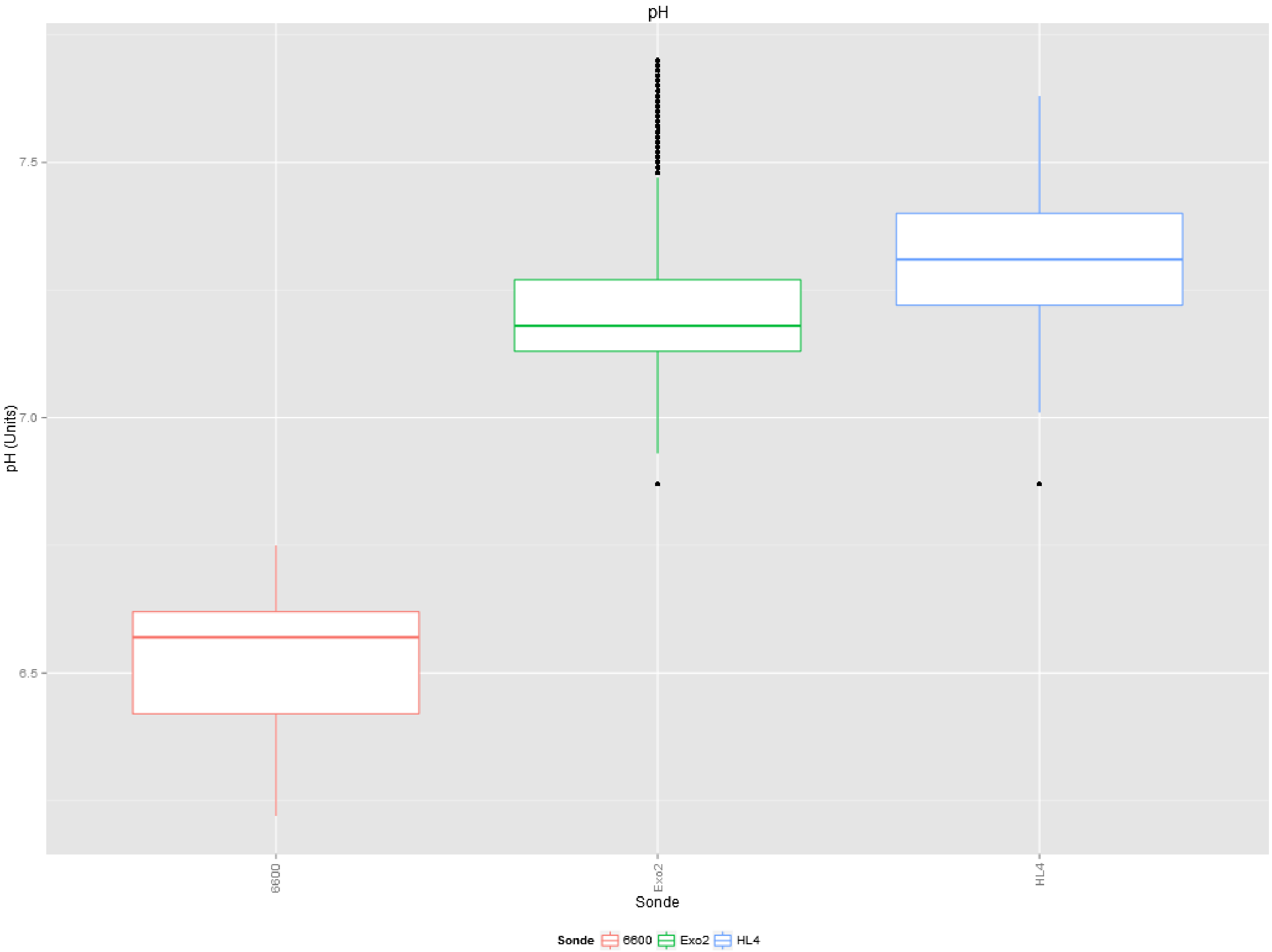


Figure 8: Boxplots of pH from YSI 6600, YSI Exo2, and Hydrolab HL4

From the figure to the left, it is obvious that the 6600 pH values are substantially lower than the other two instruments, while there is some overlap between the Exo2 and HL4.

From the distributions of the boxplots, it appears that the 6600 tends to produce pH values in a left skewed distribution, biasing towards low pH values. The Exo2, however, does the opposite – skewing right – biasing towards higher pH values. The HL4, on the other hand, produced pH values in a less-biased distribution closer to a normal curve.

Specific Conductivity

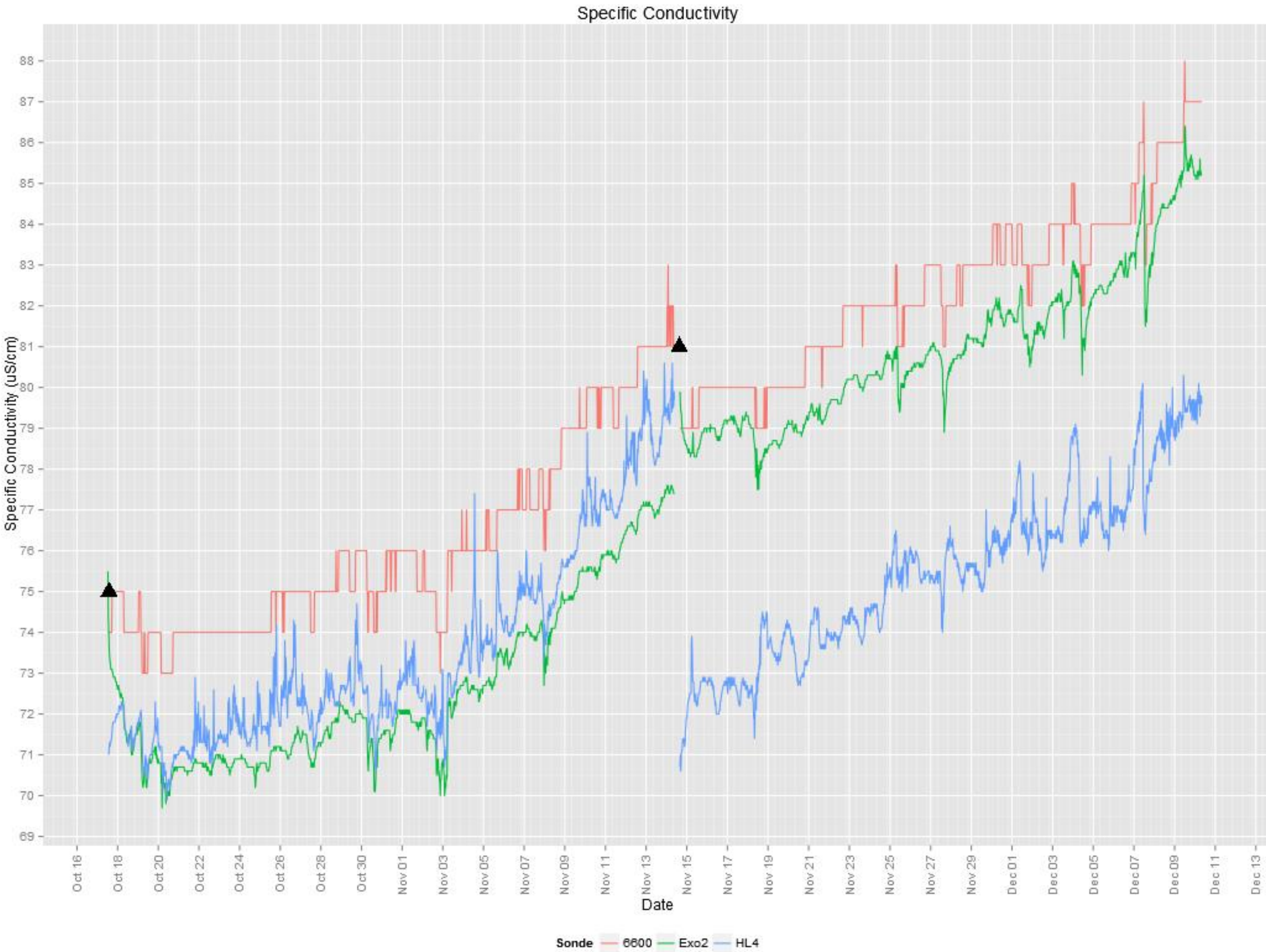


Figure 9: Specific conductivity from YSI 6600, YSI Exo2, and Hydrolab HL4

In the period between October 17th and November 14th (the first deployment of two) all three sondes showed a close agreement, although the 6600's low resolution was noticeably apparent, given the stuttered appearance of the trace. While the HL4 and Exo2 sondes report conductivity to 0.1 uS/cm resolution, the 6600 reports to 1 uS/cm.

In the second deployment, however, the HL4 showed an obvious discrepancy compared to the Exo2 and 6600. While responses to environmental events were comparable across all three sondes, the Exo2 disagreed on average by about 5 uS/cm.

Grab sample values – black triangles – fall closest to the values produced by the YSI 6600.

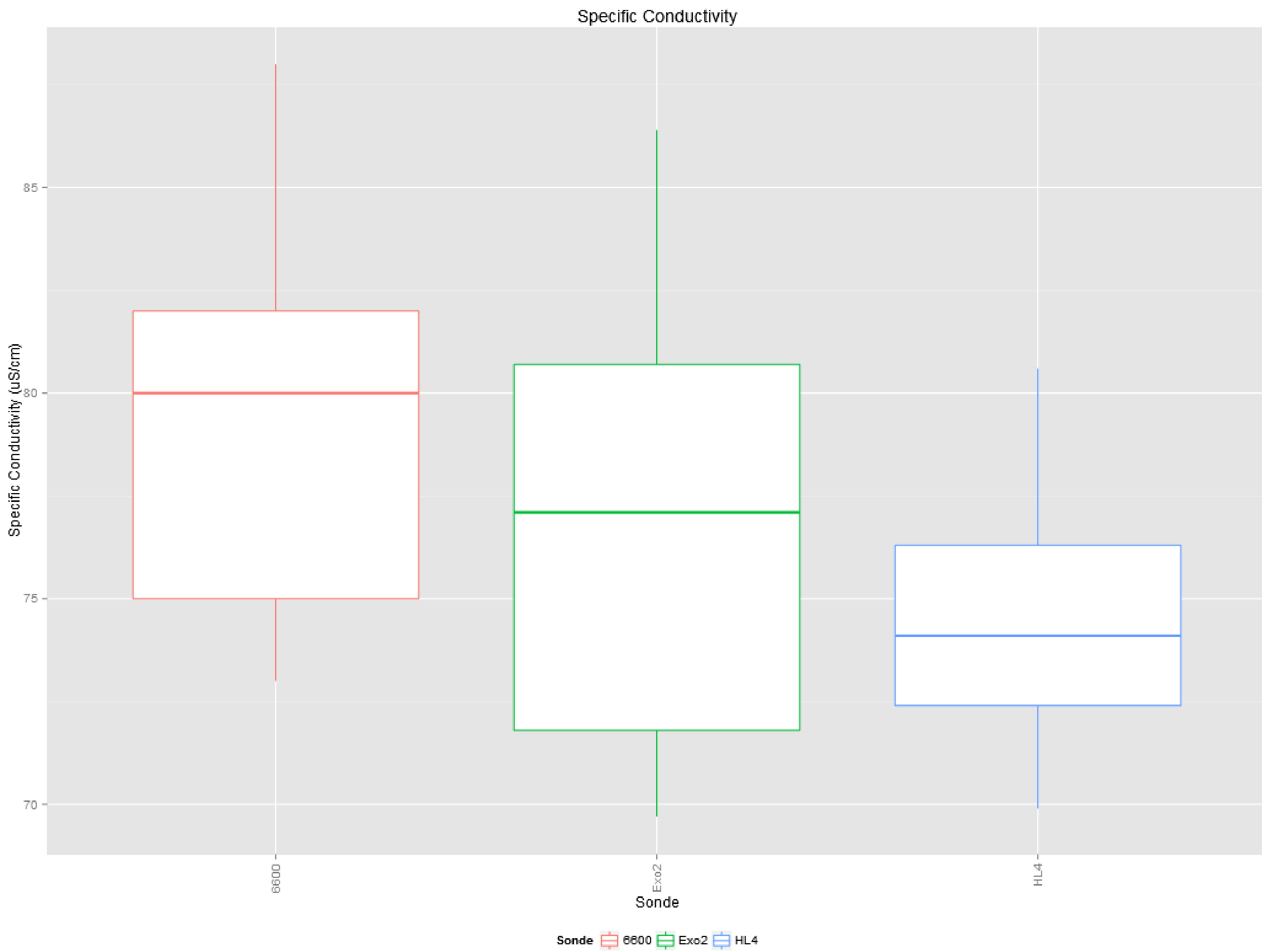


Figure 10: Boxplots of Specific Conductivity from YSI 6600, YSI Exo2, and Hydrolab HL4

Substantial overlap in conductivity values between the 6600 and Exo2 sondes is shown in Figure 6. The HL4, however, did not agree closely with the other two sondes.

Dissolved Oxygen

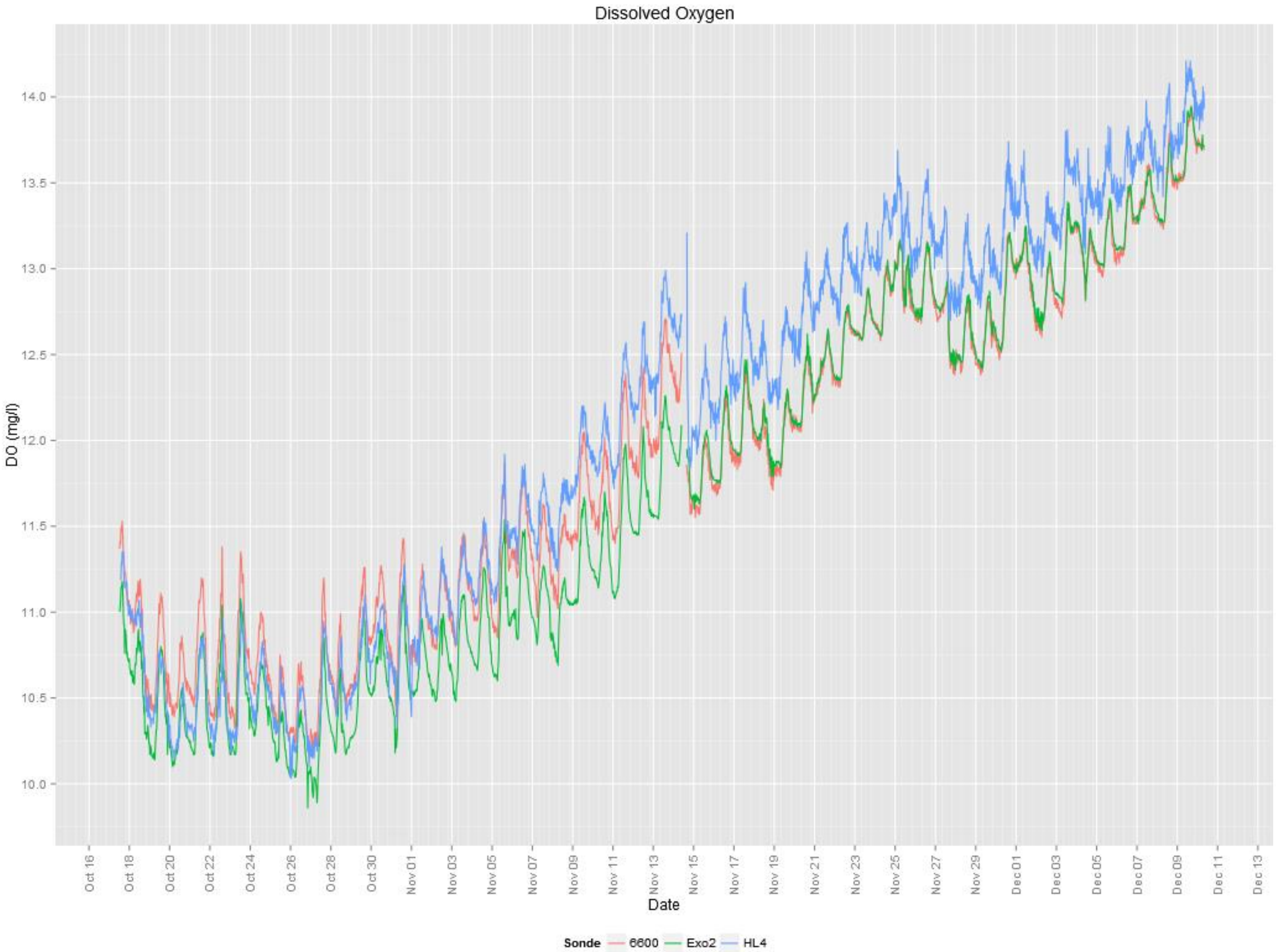
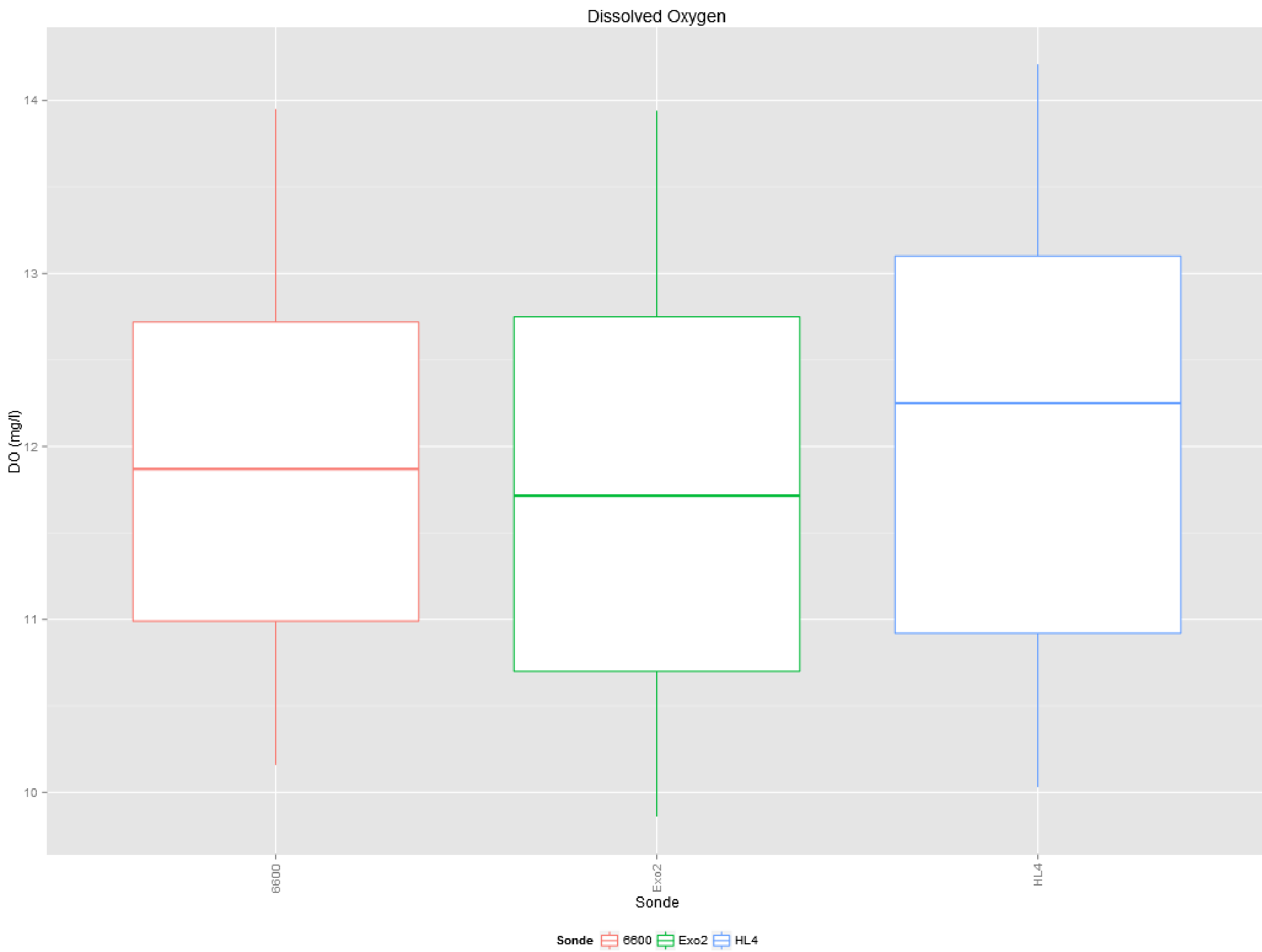


Figure 11: Dissolved oxygen from YSI 6600, YSI Exo2, and Hydrolab HL4

The YSI 6600, YSI Exo2, and Hydrolab HL4 showed similar response to diurnal variation in dissolved oxygen concentration and weather events.

Agreement between the 6600 and Exo2 was better in the second deployment than the first. Since no change was made to the membranes on either instrument's sensor the close agreement may be the result of a better quality calibration.

All three instruments showed a downward shift in dissolved oxygen concentration from the end of the first deployment into the second. This is may be due to the removal of accumulated biofouling on the sensor membranes. Also notable in the second deployment are the relatively elevated values recorded by the HL4 compared to the 6600 and Exo2.



Dissolved oxygen concentrations reported by the HL4 were often higher than values produced by the 6600 and Exo2 sondes. Median values were close for the Exo2 and 6600, although the Exo2 tended to be slightly lower in its reports compared to the 6600.

Figure 12: Boxplots of dissolved oxygen from YSI 6600, YSI Exo2, and Hydrolab HL4

Turbidity

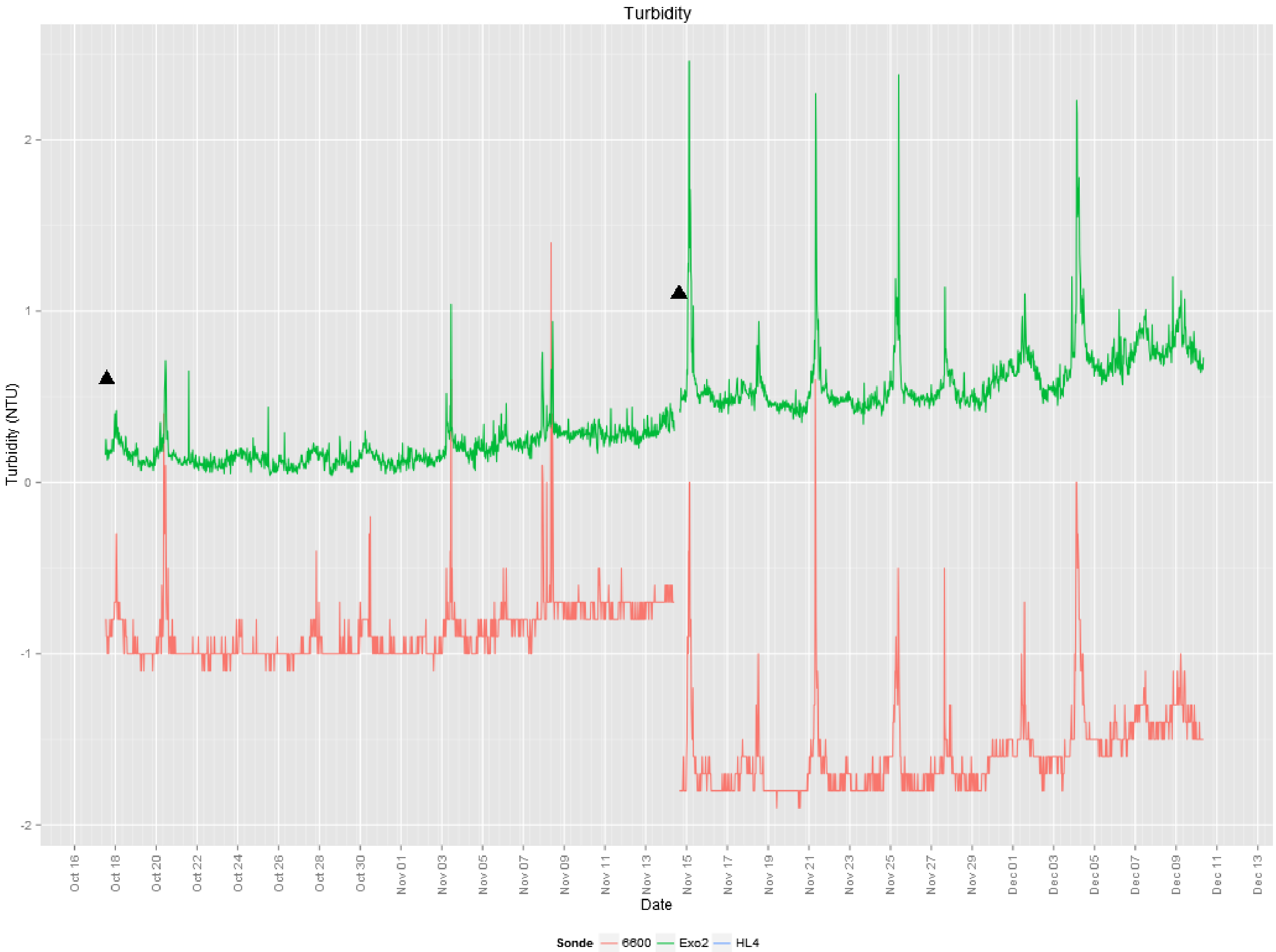


Figure 13: Turbidity from YSI 6600, YSI Exo2, and Hydrolab HL4

Peaks in turbidity response were similar between both the Exo2 and 6600 sondes. The HL4 provided for trial did not possess a turbidity sensor. While the sensors showed a similar response, the 6600 has a tendency to produce negative values which can be non-intuitive as turbidity cannot be negative. Anecdotally, it has been explained that this can be the result of improper calibration technique; however, the same solutions and techniques were employed between the two sondes.

Grab sample results, indicated by the black triangles, are closer in value to the Exo2 than the 6600.

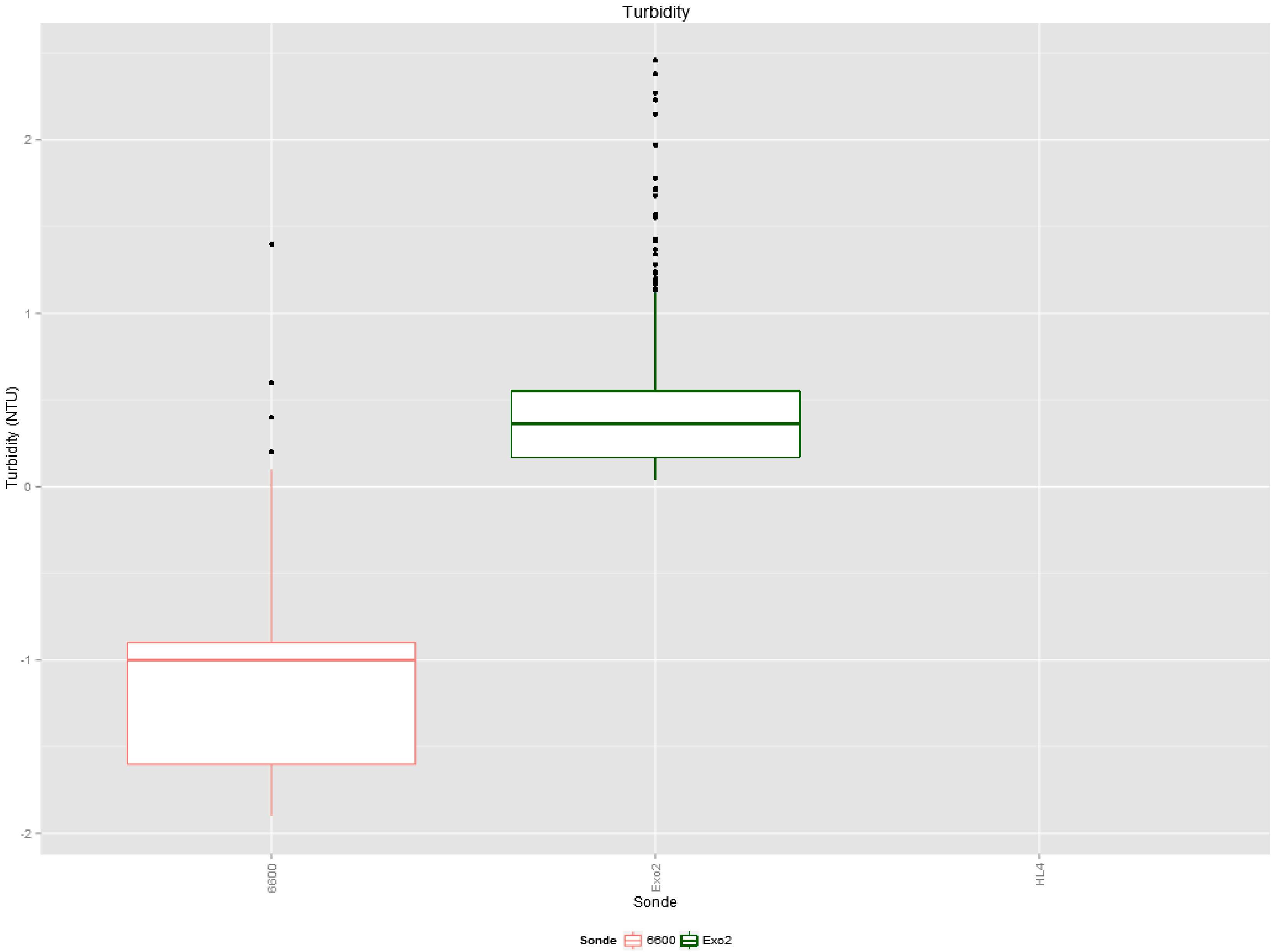


Figure 14: Boxplots of turbidity from YSI 6600, YSI Exo2, and Hydrolab HL4

While the Exo2 turbidity sensor returned values mainly on a normal distribution, the 6600 turbidity sensor was heavily biased towards lower values and mostly below zero. The HL4 is not depicted in Figure 14 due to the absence of a turbidity sensor.

Conclusions

The intention of this report is not to provide an exhaustive comparison of the instruments as time and money limitations do not permit a full study with replication. Simply, this report presents a short side-by-side comparison of data from three different instruments available at the time.

Each of the three models compared in this report have quirks to be aware of and work around when using them (see Table 2 for pros and cons of each instrument). In the case of the YSI 6600, it is behind the other two in terms of usability due to its text-based menus, unintuitive menu-structure, and unusual negative turbidity readings. The Exo2, developed as a successor to the 6600, is a complete redesign featuring Bluetooth and USB connectivity, wet-mate connectors, and well-built titanium sensor bodies. These and other features substantially simplify usage in the lab and field.

Table 2: List of Pros and Cons for Multi-parameter sondes

Item	Sonde	Pros	Cons
User Interface	6600	- Quick navigation of basic functions once menu structure is learned	- Can be confusing at first for people unfamiliar with menu structure
	Exo2	- Graphical point and click interface	- Cumbersome and unintuitive due to pictograph menu
	HL4	- Graphical is very simple and easy to understand. Familiar feel for Windows users	- Prone to error (could be due to beta version of software)
Usage	6600	- Cabling is easy to use and resistant to bending pins	- Complex setups can be challenging to set up due to menu structure - Inability to alter SDI-12 parameter order can be a source of frustration
	Exo2	- Repetitive logging tasks are easy to reproduce due to log file setup - Waterproof cable connections makes deployment simple	
	HL4		- Unexpected errors during usage. A parameter disappeared during project
Calibration	6600	- Time consuming stabilization for some sensors	
	Exo2	- Guided calibrations – very intuitive	
	HL4	- Guided calibrations – moderately intuitive	
Data Quality	6600		- Tends to produce negative turbidity values
	Exo2	- Effective use of metadata to show data quality	

The Hydrolab HL4 was developed as the successor to the DS5 series. Though the HL4 has a redesigned and intuitive user interface, it still utilizes the same sensor as its predecessor. In recent years, the RTWQ program has had considerable difficulty with turbidity and dissolved oxygen sensors on the DS5. Even though the problems appear to have been remedied by the manufacturer with recent redesigns, a trial of the HL4 instrument is not long enough to completely evaluate sensor failure rates.

There were several limitations in the comparison of the multi-parameter sondes in this project. Only two grab sample variables (deemed to be “true” representation of values) were available for comparison to the multi-parameter sondes, limiting the amount of comparisons and statistical analysis that could be undertaken. Additionally, of the three instruments compared, only two possessed turbidity probes and a pH probe failed on another. Furthermore, the YSI 6600 used had an unknown service record; sensors had been serviced in the past, but exact timeframes were not available.

In many of the preceding time-series graphs, there was a clear difference between each instrument, especially for pH, conductivity, and turbidity. However, without a reliable control group, it is impossible to ascertain which instrument is more reflective of “actual” conditions.

In assessing other variables such as use, weight, cabling, connectors, the instrument of choice is the YSI Exo2 sonde. A great deal of thought has been put into the physical design of the instrument’s casing, function, and use. It should serve as an example of how other redesigns should be approached.

Path Forward

The following are improvements that could be made to enhance future comparative assessments:

- Additional instruments should be added for comparison, such as the Hydrolab DS5X
- Regular grab samples are useful in setting a control variable to indicate each instrument's deviation from expected values
- Longer period of testing
- Ensure test instruments share equivalent sensors (in this report, the HL4 lacked a turbidity sensor)
- Ensure maintenance record is well-established for all test instruments