ctdTurbO_2: Open-Source, Low-Cost Sensors for Oceanographic and Environmental Research

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Abstract

The ctdTurbO_2 integrated sensor-datalogger is a device designed to measure conductivity, temperature, depth, turbidity, and dissolved oxygen in freshwater and marine environments. Its primary use cases are education and outreach for students at the advanced high school level, and research by undergraduate and graduate university students. It can be built in a matter of hours using tools available to high school robotics or engineering programs or in college makerspaces and materials and components which are readily available for purchase on Amazon or DigiKey at a cost far below that of commercially produced environmental monitoring instruments. This paper includes analysis of sample data collected from a local reservoir and a step-by-step guide to building and calibrating the ctdTurbO_2.

Introduction

The cost of commercially available environmental and oceanographic instruments represents a huge barrier to entry to environmental science. ctdTurbO_2 is meant to lower that barrier to entry. The Aquistar Multi-Parameter Water Quality Logger, a similarly capable environmental instrument, costs approximately 6300 dollars (Aquistar Multi-Parameter Water Quality Loggers-Standard Configurations, n.d.). The ctdTurbO_2 can be built from components with a cost totaling roughly 500 dollars. For the cost of one Aquistar, which can only take measurements at a single point, a researcher could build a whole array of ctdTurbO_2 units to study environmental processes in three dimensions. Fear of losing an expensive sensor may also discourage researchers from collecting data in environments where sensors might be lost. The loss of an Aquistar may significantly reduce a research group's data collecting capabilities, whereas the loss of one ctdTurbO_2 from a fleet of sensors would be a relatively minor setback.

A labeled picture of the probes is in Figure 1. The temperature probe is an internally calibrated DS18B20 temperature sensor. It processes its signal internally and outputs a temperature in degrees Celsius with no need for further processing (Waterproof 1-Wire DS18B20 Digital Temperature Sensor, n.d.). The pressure sensor functions similarly. Though it communicates with the microcontroller by a different serial protocol, it processes its signal internally and outputs a pressure value in millibar (MS5803-14BA Miniature 14 Bar Module, n.d.).

The conductivity and dissolved oxygen sensors are manufactured by Atlas Scientific, a company that builds environmental probes for DIY applications. The dissolved oxygen probe comes with a processing circuit that returns values in mg/L. It is a Clark electrode, meaning that it consists of two electrodes separated from the environment by a membrane that is permeable to

oxygen. Dissolved oxygen that passes through the membrane is reduced to water. The current that can pass between these electrodes is directly proportional to the partial pressure of oxygen that passes through the membrane. If the permeability of the membrane is well-defined, the concentration of dissolved oxygen in the environment can be calculated. Because the probe consumes oxygen in measuring the concentration, it lacks accuracy in stagnant water (Mini Lab Grade Dissolved Oxygen Probe, 2020). The conductivity probe outputs values in μS/cm (Mini Conductivity Probe K 1.0, n.d.).

The turbidity sensor is a VCNL 4010 proximity/light sensor meant for robotics (VCNL4010 Proximity/Light Sensor, n.d.). The sensor consists of a NIR emitter and receiver. In ctdTurbO_2, it measures in active and passive modes. In passive mode, it records the light coming into the receiver while the emitter is off. In active mode, it records the light coming into the receiver while the emitter is on. The return is a unitless value ranging from 0 to 65535 ($2^{16} - 1$). It can be used to measure turbidity and suspended sediment concentration because the active return is directly proportional to turbidity and suspended sediment concentration, so the unitless return can be converted to those environmental parameters from a straight calibration curve (Downing, 2006). Because the receiver was designed for subaerial daytime applications, it has a daylight blocker, meaning that sunlight does not make a significant contribution to the sensor return. Active unitless return from the field tests ranged from ~3500 to ~7500, whereas passive unitless return ranged only from 0 to 24, as shown in Figure 3.

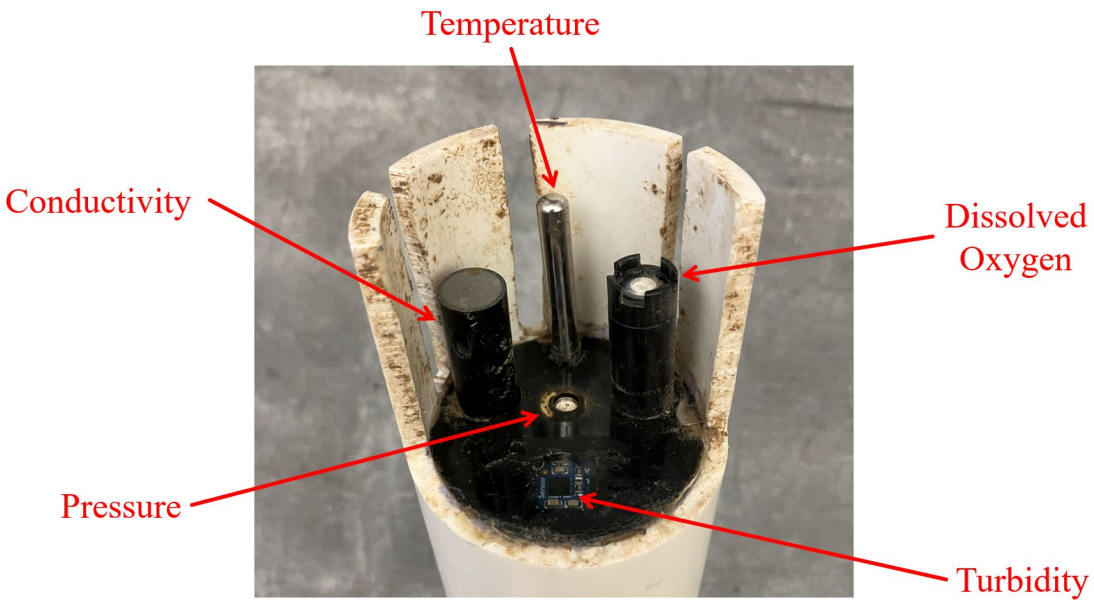

Figure 1. Labeled picture of sensor head.

Methods

Jordan Lake is a reservoir in Chatham, Durham, Orange, and Wake Counties in North Carolina formed from the damming of the Haw River in 1981 for the purposes of flood control, municipal water supply, conservation, and outdoor recreation. Jordan Lake is stratified in the summer with a warm, oxygenated upper layer and a cold, hypoxic lower layer (Cain, 2017).

The sensor was deployed hanging at a depth of 3 meters on the northwestern side of a floating breakwater structure accessed by kayak from the Crosswinds Boating Center (565 Farrington Rd, Apex, NC 27523), seen in Figure 2. Lake depth at the site ranged from 3.8 to 4.1 meters during the study period. The first deployment lasted from September 18, 2023 to September 25, 2023. The second deployment lasted from October 13, 2023 to October 24, 2023. In both deployments, the sensor was programmed to make five measurements per sampling

period with five minutes between each sampling period. The battery life in this configuration is 14 days.

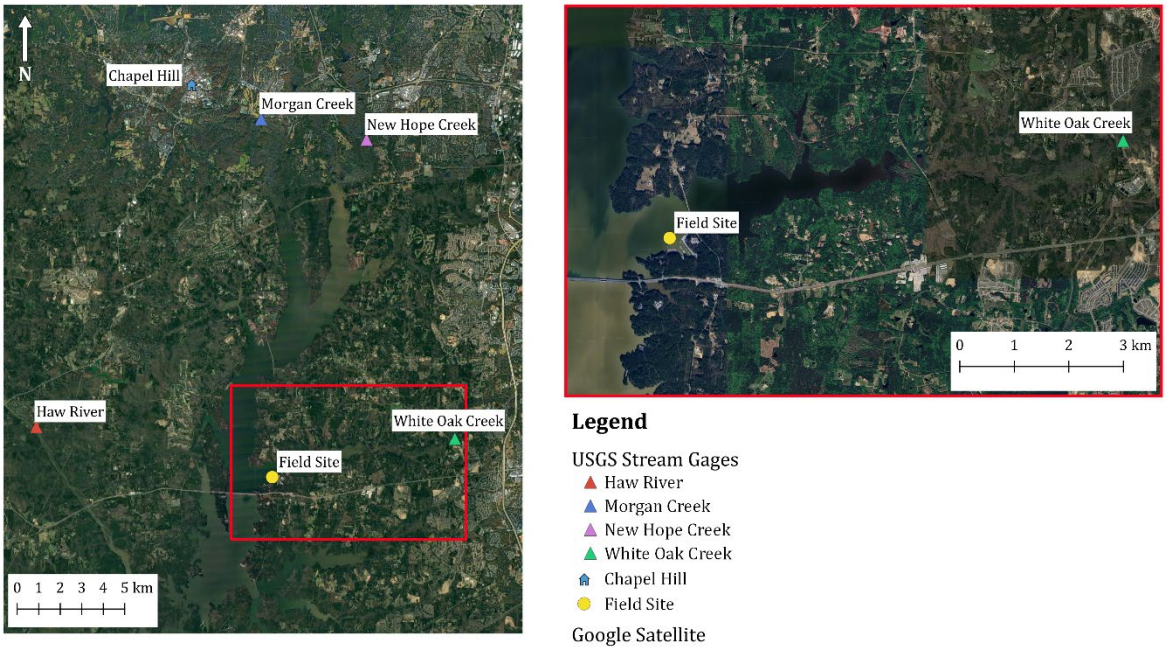

Figure 2. Deployment site in White Oak branch of Jordan Lake.

Results

Plots of all the data collected during the deployments are shown in Figure 3. Limitations of the calibration procedure did not allow for the conversion of backscatter to actual turbidity or suspended sediment values. However, because backscatter responds linearly to turbidity and suspended sediment concentration, it can be used as a proxy in qualitative analyses. The overall upward trend can be explained by biofouling on the sensor face. The growth of algae increased the amount of light that was reflected back to the receiver. Temperature had a negative slope because it was fall. Pressure remained consistent during each deployment because the sensor was hanging from a floating structure, so even when lake level changed, the sensor moved with the

water level. The decrease in ambient light (passive return from the backscatter sensor) can also be explained by biofouling on the sensor face. The peaks in ambient light occur during daytime, and the troughs occur during nighttime. The amplitude of the fluctuation decreased because the algae building up on the sensor face formed a barrier that blocked sunlight from reaching the receiver. The behavior of the oxygen values is difficult to explain, but the attempt at calibration showed that the Atlas Scientific dissolved oxygen probe is unreliable. Salinity does not vary enough in Jordan Lake for the Atlas Scientific conductivity probe to give a return.

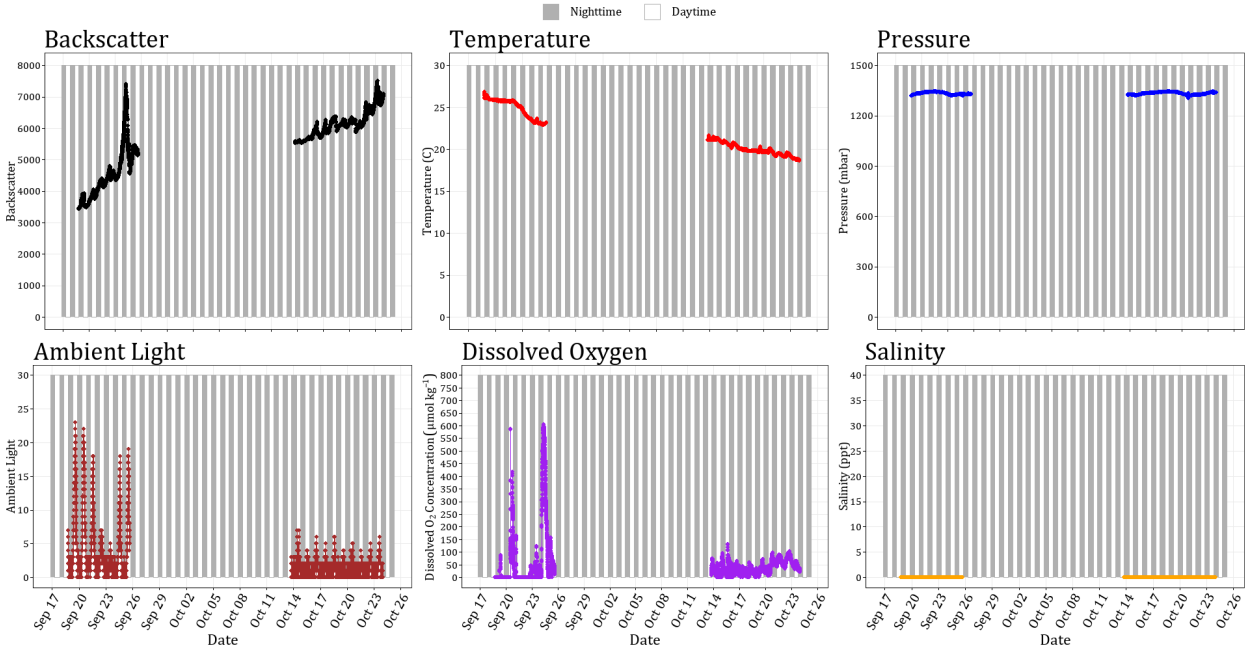

Figure 3. Compiled data from field tests. Daytime and nighttime periods come from sunset and sunrise times provided by the US Naval Observatory (*Table of Sunrise/Sunset, Moonrise/Moonset, or Twilight Times for an Entire Year*, n.d.).

Fourier Analysis

There is some periodicity to the backscatter data, but it does not exactly follow day and night. To find the dominant frequencies for variation in backscatter during each deployment, I followed these steps:

1. dt is not consistent because the sensor takes 5 readings every ~5 minutes. Create a new time series with dt equal to 600 seconds by taking the mean turbidity over 10 minute periods.
2. Remove the trend from the data.
3. Apply Fast Fourier Transform.
4. Plot modulus of fft against frequency.

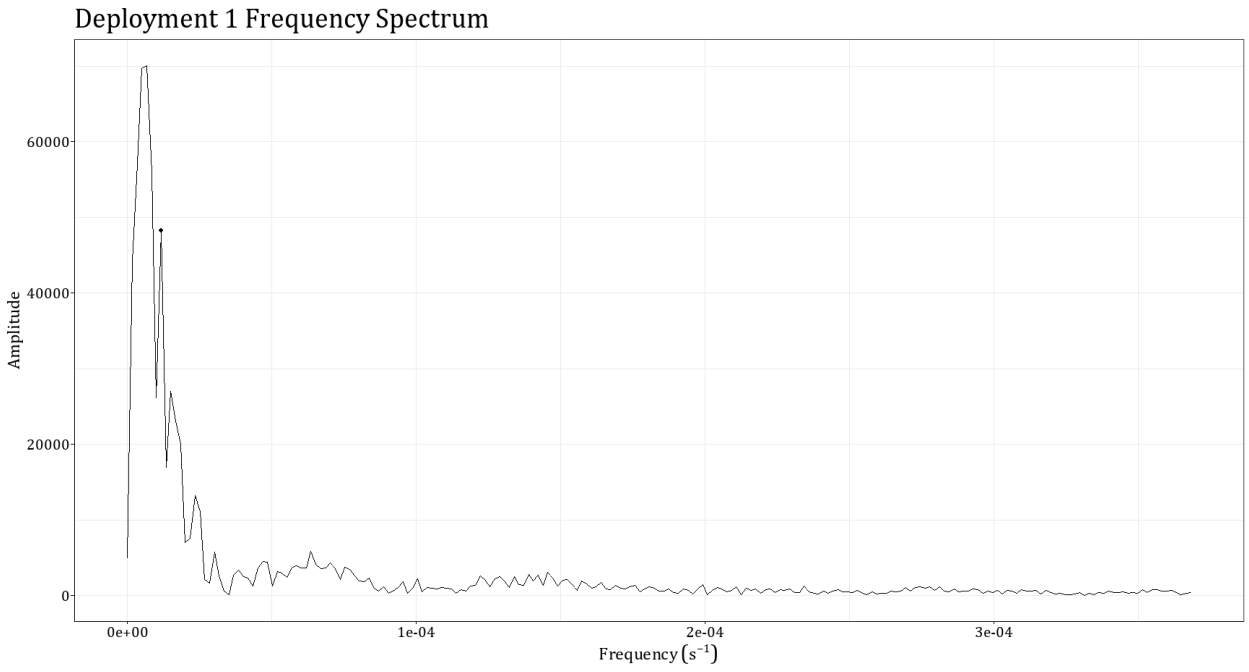

Figure 4: Deployment 1 Frequency Spectrum.

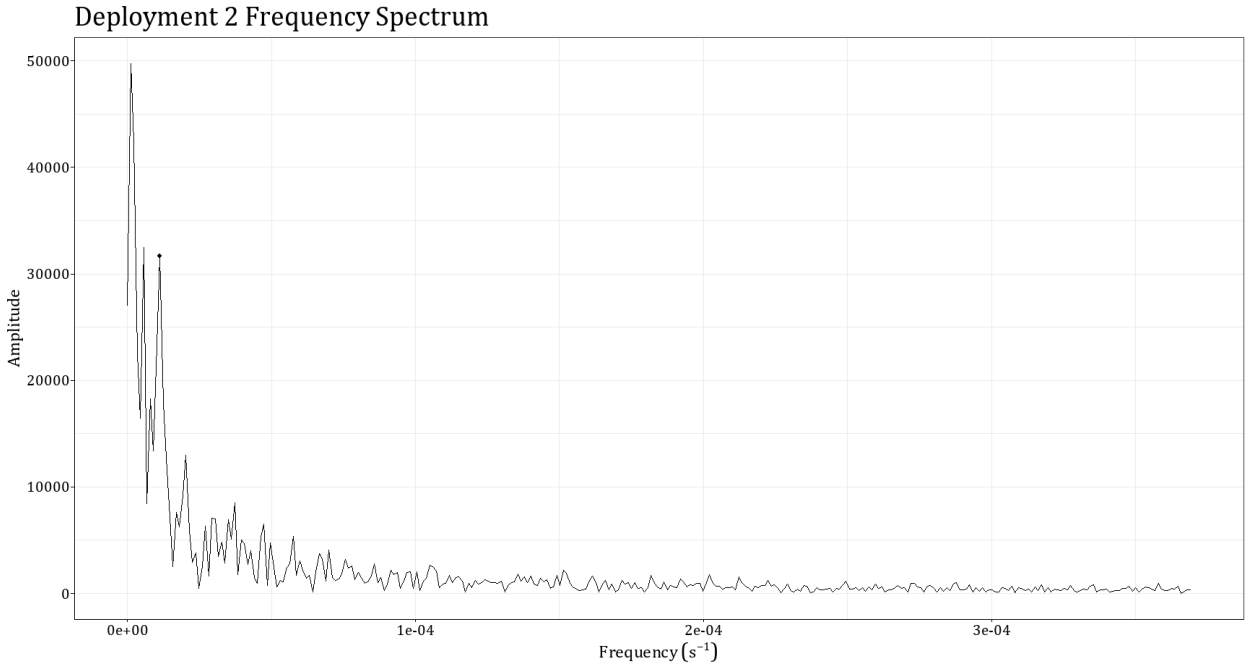

Figure 5: Deployment 2 Frequency Spectrum.

Note the emphasized peaks in Figures 4 and 5. Those peaks correspond to frequencies of 1.178e-5 s^{-1} for deployment 1 and 1.117e-5 s^{-1} for deployment 2, which give periods of 0.982 and 1.04 days, respectively. Tests at room temperature and 4° C have shown that temperature variations do not cause the clock in the ctdTurbO_2 to drift. This change in periodicity cannot be attributed to clock drift caused by the seasonal change in temperature.

Principal Component Analysis

USGS maintains streamgages on the White Oak Creek, Haw River, New Hope Creek, and Morgan Creek, all of which flow into Jordan Lake. Locations of each streamgage are shown in Figure 2. All four streamgages collect data on river height and discharge every 15 minutes (National Water Information System). I downloaded the data for September 18-25 and October 13-24 and converted the height and discharge values to metric units. To make the timestamps fit

together, I created a new matrix of sensor data with timestamps matching the USGS data. Each row was populated with mean measurements of the 15 minute window that ended with that row's timestamp. I combined the matrices by timestamp and removed 25 hours on September 22-23 when the New Hope streamgage malfunctioned and returned NA. I removed the conductivity column because it was all 0's, and it caused errors when scaling the rest of the matrix. The dateTime column was removed for this analysis.

I identified the principal components using the following steps:

1. Scale each column by subtracting the mean and dividing by the standard deviation.
2. Calculate the covariance matrix of the scaled dataset.
3. Record the eigenvectors and eigenvalues of the covariance matrix.

I produced a screeplot of principal components to see the weighting (Figure 6). The first eigenvalue does not rise particularly high above the rest, but the loading composition of principal component 1 is particularly interesting.

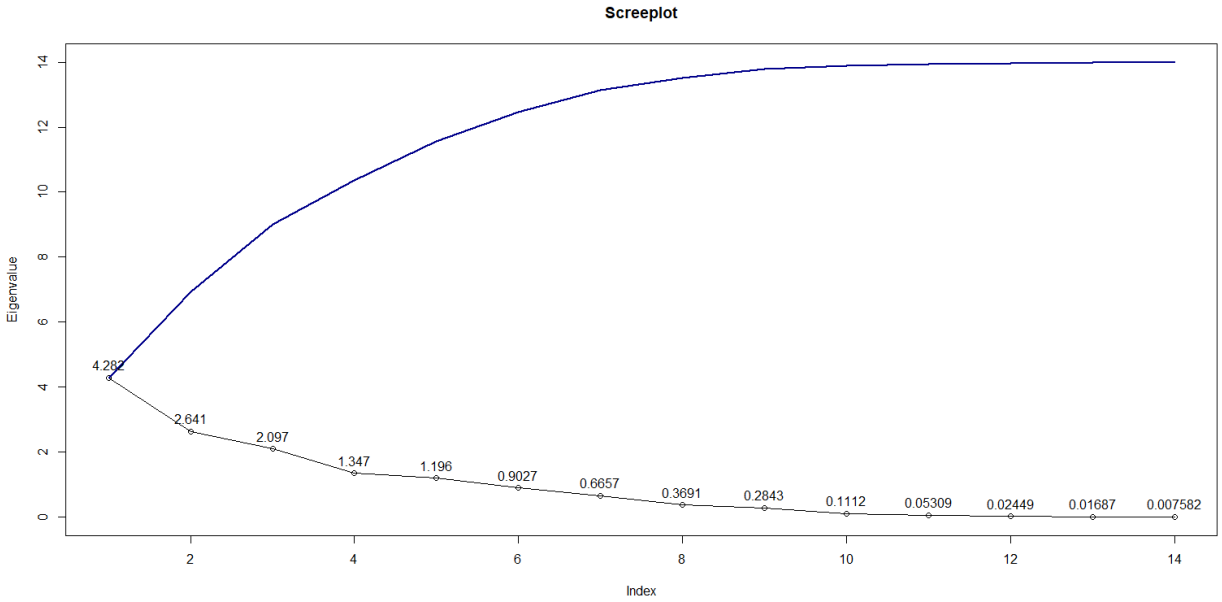

Figure 6: PC1 Screeplot.

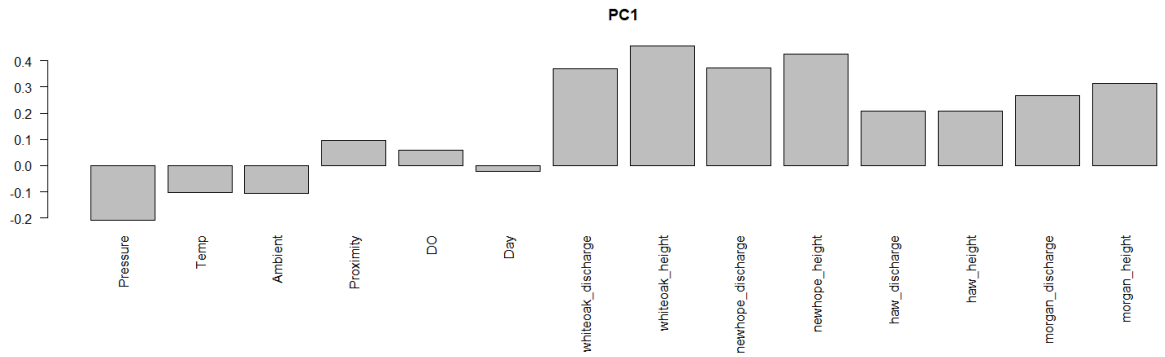

Figure 7: Principal Component 1 Loadings.

In PC1 (Figure 7), the backscatter measurement and all of the river heights and discharges are positively related. This makes sense because the large peak in backscatter during the first deployment roughly follows the peaks in tributary discharge.

Conclusions

With this analysis I have identified a component sinusoid in the backscatter data with a period close to 1 day. I have also calculated principal component axes relating tributary discharge and water level to the parameters measured by ctdTurbO_2. In the first principal component, there is a very strong correlation between backscatter and periods of increased discharge. My hypothesis is that tributary discharge and backscatter are so closely related because tributaries have enough energy during storms to bring plumes of sediment far into the White Oak arm of the lake.

Constructing the ctdTurbO_2

Bill of Materials

Components			
Part Name	**Amount needed per unit**	**Cost per unit**	**Link to purchase**
Adafruit Feather M0 Adalogger	1	$ 25.63	https://www.amazon.com/Adafruit-Feather-M0-Adalogger-ADA2796/dp/B01BMRDBXW/ref=asc_df_B01BMRDBXW/?tag=hyprod-20&linkCode=df0&hvadid=167151358503&hvpos=&hvnetw=g&hvrand=14021805013797778224&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9009671&hvtargid=pla-302797437076&psc=1&mcid=a186c88ae60c3f99aed730fd22ba9ad6&gclid=CjwKCAiAzc2tBhA6EiwArv-i6Rt6y63QvgDN8yZCtvFjZyFbA5WBW4mSZjKNZsdTV5Z0nTQcqKXCzRoC_kUQAvD_BwE
DS3231 Precision RTC FeatherWing	1	$ 13.95	https://www.digikey.com/en/products/detail/adafruit-industries-llc/3028/5885910?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Low%20ROAS%20Categories&utm_term=&utm_content=&utm_id=go_cmp-20243063506_adg-_ad-__dev-c_ext-_prd-5885910_sig-CjwKCAiAzc2tBhA6EiwArv-i6fb-u-XN80XwzFgq0mxfS5GfW3AE3wW9xzTpCBPfb9YBkhKhK88E-BoCPjcQAvD_BwE&gad_source=1&gclid=CjwKCAiAzc2tBhA6EiwArv-i6fb-u-XN80XwzFgq0mxfS5GfW3AE3wW9xzTpCBPfb9YBkhKhK88E-BoCPjcQAvD_BwE
Female header pins	1	$ 0.16	https://www.amazon.com/Qunqi-2-54mm-Straight-Connector-Arduino/dp/B07CGGSDWF/ref=sr_1_21?dib=eyJ2IjoiMSJ9.zeC41QqtTZlhxSknrJPJDpSeSsjI8ShuLcBIB1Hp-oNt8dC99VC4Xqi81KRclh0rcjbN4SdeoGnyxJdTrbeg7VkeoYCrfEl77RqVSprO3RGWqHf6ZPY9dh3QsER6agKscC1SEv5RZeb88blhC1WNcHdlBeJn3BXrN3ozLce6k0q81blCWrdHvZk4G7-kc65nprQdih3A1klO-g6ilHP34mnnPqWqT8TvWHpw0FVvqdg.E-N27OAGegN3NQt3WOlOoTQjg2WFKiT-8_GX293rhwM&dib_tag=se&keywords=header+pins&qid=1713929661&sr=8-21
Custom PCB	1	$ 0.44	File in project GitHub: https://github.com/whererediddavidgo/ctdTURBO
Atlas Scientific EZO-DO	1	$ 52.99	https://www.amazon.com/Atlas-Scientific-EZO-DO-Dissolved-Embedded/dp/B0078WUJUO/ref=sr_1_6?crid=27AXNFOTU

Dissolved Oxygen Embedded Circuit			DLXC&keywords=atlas+scientific+dissolved+oxygen+ic&qid=1706288890&sprefix=atlas+scientific+dissolved+oxygen+ic%2Caps%2C101&sr=8-6
Atlas Scientific EZO-EC Embedded Conductivity Circuit	1	$ 53.99	https://www.amazon.com/Atlas-Scientific-EZO-EC-Embedded-Conductivity/dp/B006ERPKLM/ref=sr_1_1?crid=OPLTHHZT3P8Q&keywords=atlas+scientific+conductivity+circuit&qid=1706288962&sprefix=atlas+scientific+conductivity+circuit%2Caps%2C88&sr=8-1
5200mAh 3.7v Lithium Ion Battery	1	$ 16.98	https://www.amazon.com/Rechargeable-Batteries-Electronics-Equipment-Bluetooth/dp/B0B1JKSY46/ref=sr_1_2?crid=2BPMRJYDT645M&keywords=3.7v+4400+mah+lithium+ion+battery&qid=1706289245&sprefix=3.7v+4400+mahlithium+ion+battery%2Caps%2C77&sr=8-2
CR1220 Battery	1	$ 1.35	https://www.amazon.com/Energizer-CR1220-Drain-lithuim-Battery/dp/B003CU3E2Q
10kΩ resistor	3	$ 0.30	https://www.digikey.com/en/products/detail/yageo/MFR-25FRF52-10K/14626
4.7kΩ resistor	1	$ 0.10	https://www.digikey.com/en/products/detail/yageo/MFR25SFTF52-4K7/9144664
22 Gauge Solid Core Wire, multiple colors		$ 14.99	https://www.amazon.com/TUOFENG-Hookup-Wires-6-Different-Colored/dp/B07TX6BX47/ref=sr_1_9?crid=1ZMRWROPA0SOC&keywords=solid%2Bwire&qid=1706296363&sprefix=solid%2Bwire%2Caps%2C125&sr=8-9&th=1
0.1µF capacitor	1	$ 0.24	https://www.digikey.com/en/products/detail/vishay-beyschlag-draloric-bc-components/K104K15X7RF5TL2/286538
Slide switch	1	$ 0.76	https://www.digikey.com/en/products/detail/e-switch/EG1218/101726
JST 2 pin connector kit	1	$ 0.60	https://www.amazon.com/Letool-Electrical-Female-Connector-Cables/dp/B07FP2FCYC/ref=sr_1_6?crid=2FUW4W08PL71T&dib=eyJ2IjoiMSJ9.WYMEkw715qL4RvpHau0KO97dL57t8_T8zlkMuoFvMGfaGeMHBXLbfConL9ITnUtlvMX4jia8JdYogiHyi1ygL3pQuCHuu-rpOnwMyE6R3zIuUnnK__SWbtZH3RONCLOzBBSn3WMrt19u-89GJj5he2oyu2mku-7UnOf3XlGhypyWptXPyH1B02LSmBNo9Hed_vgJkS4hGugyV8Ql3iXNhG04JEdL_Llcald1TcXk-FI-5yNAjG2D8IvO81NOEuD9N_Oj6BogMKeuO7jN0U7e1w7xINidX1CGBdhgdJl4PIQ.hiPBzg17XdRPkA-SCYbTnrI16Wdiq9ZR4s-KuWjiwos&dib_tag=se&keywords=jst+connector+2+pin&qid=1708363190&sprefix=jst+connector+2+pin%2Caps%2C97&sr=8-6

Atlas Scientific Mini Lab Grade Dissolved Oxygen Probe	1	$ 134.99	https://www.amazon.com/Atlas-Scientific-Grade-Dissolved-Oxygen/dp/B08MB98D98/ref=sr_1_7?crid=3VPV4J3JBHT8L&keywords=atlas+scientific+dissolved+oxygen&qid=1706288740&sprefix=atlas+scientific+dissolved+oxygen%2Caps%2C88&sr=8-7
Atlas Scientific Mini Conductivity Probe	1	$ 123.99	https://www.amazon.com/Atlas-Scientific-Mini-Conductivity-Probe/dp/B08MBDSRS1/ref=sr_1_1?crid=3BGKEIWRDR3EC&keywords=atlas+scientific+conductivity+probe+mini&qid=1706288927&sprefix=atlas+scientific+conductivity+probe+min%2Caps%2C88&sr=8-1
DS18B20 Temperature Sensor	1	$ 2.40	https://www.amazon.com/HiLetgo-DS18B20-Temperature-Stainless-Waterproof/dp/B00M1PM55K/ref=sr_1_3?crid=353SAGDJ2CYV4&keywords=ds18b20&qid=1706294825&sprefix=ds18b20%2Caps%2C117&sr=8-3
MS580314BA01-00 Pressure Sensor	1	$ 20.93	https://www.digikey.com/en/products/detail/te-connectivity-measurement-specialties/MS580314BA01-00/5277631
SOIC DIP 8 pin adapter	1	$ 0.88	https://www.digikey.com/en/products/detail/sparkfun-electronics/BOB-13655/5528943
VCNL4010 Light Sensor	1	$ 7.99	https://www.amazon.com/RAKSTORE-VCNL4010-Proximity-Sensor-3-3-5V/dp/B0CMD33Z24
3D printed endcap	1	$ 15.00 (assuming ordering)	File in project GitHub: https://github.com/whererediddavidgo/ctdTURBO
2 inch schedule 40 PVC pipe	1 ft	$ 8.20	https://www.amazon.com/2-1-Schedule-40-PVC-Pipe/dp/B0C549J61Q/ref=sr_1_3?dib=eyJ2IjoiMSJ9.lLkbbiHC-UM838uloj4kxOoq0FA7PIgPnI32O0ML1I0PsfmWeDoOaRttdeRBp1jqranp4npfFpN5Mkj6wZrN8YOLxwNVrgD3kMbUXy9m1edbYsBQU0lzEkhKRk8trfgaN7LQ6Kkmk2W8tU0kG0mT8pUNiL6FSJ7RU3VHSl2KZuqSpShfkX6xg67FmLTYgsyHGfemF5aPH9GN6Rcx_J3zRDsd_4wAI57UArT6xTpljkU.fYNhwgk9PWE_WGepavnQf9ooEY3XslnsK8LUsCVYyt4&dib_tag=se&hvadid=580698540421&hvdev=c&hvlocphy=9009671&hvnetw=g&hvqmt=b&hvrand=12144238504636210897&hvtargid=kwd-297414241090&hydadcr=26723_11679469&keywords=2.5%2Bpvc%2Bpipe&qid=1708358278&sr=8-3&th=1

2 inch test plug	1	$ 5.29	https://www.amazon.com/Pipe-Plug-Mechanical-Size-270229/dp/B000R84XB2/ref=dp_fod_sccl_1/130-0467246-4453621?pd_rd_w=fresk&content-id=amzn1.sym.550e945f-c48e-4794-aff0-cc9017996f0a&pf_rd_p=550e945f-c48e-4794-aff0-cc9017996f0a&pf_rd_r=45SVDV7J93FVP5HQNENC&pd_rd_wg=YCEMr&pd_rd_r=e72d5f86-fb2f-4c25-bf75-ddb6c3b56b92&pd_rd_i=B000R84XB2&psc=1

Consumables		
Material	**Cost**	**Link to Purchase**
63-37 Sn Pb rosin-core solder (0.8 mm)	$ 8.99	https://www.amazon.com/MAIYUM-63-37-Solder-Electrical-Soldering/dp/B075WB98FJ?th=1
Electrical tape	$ 2.78	https://www.amazon.com/Scotch-Heat-Resistant-Listed-Certified-Electrical/dp/B001AXD0EY/ref=sr_1_3?crid=3V00BT32HDRM9&dib=eyJ2IjoiMSJ9.jhfH539qq2ZFd-E-e0W42iekDFlntRPhKLMR9_mZ6_wq6xrLonU115DN8iyXNNy3rMb31abU4jpsPUSmBvcqa3a0XdGkAAdelM8uyBPHdiHrsNwz6gfiOXfSEUL77wEBqvXUsO6-SSE5dHgIqdQLE8EkorabVAAD7OTW5bQ8FvqoCcUzIGHtZ3k3f2DPdbrBHKKnQHwuio0mjNjwOSNAc5QLbkr9AM-COBmvC0YxYqyv2ZPmoWwD8mN54t1m_yTMqaV_03aMIHQ11Hxqiay8kfUmpIX_YPQwLL3TmTEUht8.gwkJH2i_3N7Sop4bQAdTgQpvE3corUpl0bhRnsFubBQ&dib_tag=se&keywords=electrical+tape&qid=1714390831&s=hi&sprefix=electrical+tape%2Ctools%2C126&sr=1-3
Teflon tape	$ 5.99	https://www.amazon.com/Inches-Plumbers-Plumbing-Plumber-Sealing/dp/B091913Z7F/ref=sr_1_3?crid=BHIHT2IVO1C5&dib=eyJ2IjoiMSJ9.BL0AU7vb2QxItOEcemms_GpcMNkkqmor-MhGN5lUe2QtLTRzoOJUeSswZkNZ5Ucv2Fb7AvHk7MP6YA4AN-Pl7aBTVspsDE5S6tEFL_hKqGIQIzhQ1xmdn5tGMnXfo2qL_Khi5INoT41SCdBfePqIttF_mDlqjWzRI9cX03z_ZZrGomODJWg0QFUpGVhdnCZvdPSQsywZxcEePkSlJ_MKuyH0v968y2TMvWWf6ZF4ZsQLlnm5lmtnK0kICbuYOtoaiqeflD7W05o_EMl-uDLndEikn5_7dmzZSIXq5_VOdZ8.mD_BrePDgBhxwqx2R4of6h8B0m0nOBOkeb83oZcYwXk&dib_tag=

		se&keywords=teflon+tape&qid=1714390863&s=hi&sprefix=teflon+tap%2Ctools%2C164&sr=1-3
VViViD optically clear epoxy	$ 33.99	https://www.amazon.com/VViViD-Optically-Clear-2-Part-Coating/dp/B079Y9QFQS/ref=sr_1_2?crid=BZ8RP3RC6UEG&dib=eyJ2IjoiMSJ9.MVjpQttatbyrO4nbXosC6wH-6aR9jvSlvgdcL2FrZpTGjHj071QN20LucGBJIEps.P_Uz_bNKffir8unOqNY9OHWvOwby--_k0eV-_-dJtrM&dib_tag=se&keywords=vvivid+scientific+epoxy&qid=1714390927&s=hi&sprefix=vvivid+scientific+epoxy%2Ctools%2C104&sr=1-2-catcorr
5 oz paper cups	$ 16.19	https://www.amazon.com/Clawsoff-Disposable-Bathroom-Mouthwash-Barbecues/dp/B0BXD8L2W7/ref=sr_1_8?crid=STW2MDTAGSAE&dib=eyJ2IjoiMSJ9.uEB5KMnB8wf0uW9Rnb315yrd9j13CTP8jLQCGA8pIR6-xm6Lb8WUsyoOSC2Uy3_Cd77Ifxc2e9-CNkSC_8XBrlN4zemrqZwqOJdTtdSVXe9KJ_VoebQhZCYGFHuD5WKjQAlXJaRcbqB1paj0P43tbv3AqKd8qWy_4c6LA_HO_snvo3mQJUqgB5pp_EG_uTBdtC0-CcxZL7C0HLWNiwFEcn3TTN32-47Apbhe3EyQP8SUzXsFPNETZVs4s2jT4dXuYefdD8NlNz6XeYtcLx9dSaHjuDmrSbIsVshBGNMHk2Y.G1nc-eJ0Gg7aQTpl4k4kSTYSezZeACTc3cym4xjDAfg&dib_tag=se&keywords=5+oz+paper+cup&qid=1714391311&sprefix=5+opaper+cup%2Caps%2C141&sr=8-8
Popsicle sticks	$ 4.99	https://www.amazon.com/Sticks-Natural-Popsicle-Length-Crafts/dp/B07F367TCK/ref=sr_1_6?crid=3SITLBWCK29H3&dib=eyJ2IjoiMSJ9.qwpP1PKXNu5yTgtrOeb6tNzTMC0I_w_IpGXL7l5Hm-siethLbnm3uzBoaL65TjQaBM_wk0EV-wSSmVE32FS3HgVzk0DhqJlleIVf2kgUxineziB5rAixqxRsIToEPkSgEN8CrpcczAixY3Kabonq6BYs8PNTsWb6YQCakkZX4xpaOUS266hHiuAcIOc0x8gcBBBdrlcrwjIvrgEt4yXSGgX7akz37VoMsslPVeihHO0BUg0FXnhrH6Grm3qHVUW-zcTFdlWjKMe_oMOeSnuTxM3yc4-1jG5zQ6-nWewHgFc.60Ye1HVbJLR_dfCTcysgLOlZnOC1OonFO1U9LTmz9i8&dib_tag=se&keywords=craft+sticks&qid=1714391373&sprefix=craft+stick%2Caps%2C235&sr=8-6
PVC cement and primer	$ 4.88	https://www.amazon.com/15900-Regular-Bodied-Plumbing-Solvent-

		Cement/dp/B0BWZ257RX/ref=sr_1_2?crid=3L9W5GB1S13K7&dib=eyJ2IjoiMSJ9.RsgqU2kVth-EfVs8Dsb0MCNCUVsl8kkfs0Vv-Rx_fDgxgsbEiasY3YmVaoUNVoJsOvDUGzvlZ-RDEsL_ekPmsRYjhVWG4MI9nDNLjdscbocFo1Fste0cMqznTFcw1NDSxgcnRaSoT_JXvglTCHSndmAxR3fc7o7HQkjq1u7DmKRbrn_VwpPLtW_hx-KuaZ_kPWg3J3JT2JSN5D25kWB0dMbqNl-PusAKZ5dgXhzt1Fk.CFRSi_O6XQ4GqDYryrb_EWz-ubWQiO6-DexWstPDsRw&dib_tag=se&keywords=pvc+cement&qid=1714391774&sprefix=pvc+cemen%2Caps%2C167&sr=8-2
Nitrile gloves	$ 7.90	https://www.amazon.com/Supmedic-Nitrile-Disposable-Powder-Free-Latex-Free/dp/B0C9S5PMSD/ref=sr_1_7?crid=RM62N1C9670W&dib=eyJ2IjoiMSJ9.pJbPEyfoKKOtokhCnZ-Y94R_hJ6rLVnyo7jNHMIDEEf1-YNayxJhjeHd-vKacuWybfNO9tFD-Ld6JQhR-u2Pj2neH5aXvxPI_lwseoysJRTtvPYY6RdZHGcELEO8qNdRqcr349Z3BM8BBGktIrDg-i-2oRAVN5ettbWiUxMYJlqY2dSZOGGrpNW7YDWFdsxM-Vf3wQ4FiLi3FP9NC7h6fIfYn4b-t5llsRZfWSJr2UKrMMK-L9lNF4jY0URO0lJK87AK9POPP_X87a3CDmivXP1rq5BT3Khdu845V6oDboI.8pCB5F7Gk0DPCMCPEaD06bKy8au8BS0UP86oyyy-AnQ&dib_tag=se&keywords=nitrile+gloves&qid=1714391832&sprefix=nitrile+glove%2Caps%2C148&sr=8-7

Tools		
Tool	**Cost**	**Link to Purchase**
Soldering iron	$ 12.98	https://www.amazon.com/Liouhoum-Auto-Sleep-Adjustable-Temperature-Thermostatic/dp/B08PZBPXLZ/ref=sr_1_6?crid=2APGUW44L95QE&dib=eyJ2IjoiMSJ9.yZ1RJBZdL8puTuRSlwFJ-_s5Hsm3ryTWRybu1aY3_X64UpUA0_0RnhUwC8ibWzQOfTQgS7zeAnAad_jgNYLjC8P1aEyAtZUez4ljtPR0RoRVE4PaM48QGr3GwujJsiF8ONHfzF2peHCOQC1El_8griAbcjvCBLwjgFdKQQ1EdV7jZE_Wg9s2VW3Kino6EeEka_XOZWjqXj54zBFDqEb_tDrLTJ-fkjSL3XgmOLxmqdfh-Nrg9Q17RlQ32WesA-A_2_z5wWReRz8m2k-qwXJm4KK-i0qPhkWSkd_zg4dZb7M.PvvEg7stUFhV76Hz_VhcaYb-

		R3FxnvqKEUt-xwrY48w&dib_tag=se&keywords=soldering+iron&qid=1714391153&s=hi&sprefix=soldering+iro%2Ctools%2C191&sr=1-6
Heat gun	$ 16.99	https://www.amazon.com/Yeegewin-Reflector-Embossing-Wrapping-Stripping/dp/B09MCZNY5J/ref=sr_1_12?crid=37IARTLOP46FK&dib=eyJ2IjoiMSJ9.co0U3lIYlKg3LtsXlK-WMyh1-MNFBAOcSASNqoUDArFp8Hy-XjdwYTQqzlITTz-F3gBGymNIoSaj8XlsfRxC0iKChgLU9vr8slwAhX290cEUBnITyD58ryf6xH0baotNDnjJVWTKhDpC--HJdUkwHp4_-gI8gDogAZcpha17bHUUO_TyIx8r30-Un6gZ7qRfeqnZL3BChYTEbqF6x3KsyLXzQt-ZoXghwOTfHffqcZGixal_k7FDDdi2MLdbJa1alhIFzmaFOH5PbW17ynLzQwCWHVQdlnlhZzsH6il1vqc.woc57RqTUjH8LWyr3fipmuyhzGIlJfEkDd4QXxbblgI&dib_tag=se&keywords=heat+gun&qid=1714391200&s=hi&sprefix=heat+gu%2Ctools%2C233&sr=1-12
Glossy silicone mat	$ 6.71	https://www.amazon.com/Silicone-Jewelry-Casting-Multi-Purpose-Placemat/dp/B07XFJ5YKN/ref=sr_1_2?dib=eyJ2IjoiMSJ9.xhhm75f1f2OpJmHpT26mWHXGYk6Msov__hrKq-AW5L0kjNTln5z_90yqLHDXFI2vIkyIkKPRQeAuRGuWNlLmKbf8qOyi8Yh3VW-l6hP2JIvzky4PBaJSHndcmmRRYoMegGPb84pNm1N1vh-yK4pa5tSpv1HV_7RZULYAqfgNVv9x4u71wUkAoL7rervjeLFG7JVh7zwokjrDUbofOAKVlwSZ7WmDUYl_JBKDFWapPebZCYfDKOp6DU70QKpU2OYONbR4sKfHkT2cOpQ3_sv12FHSnCpoADyj9pU_o7WLyj4.a9_ptiLeY3zFU2fR4jzOCsupIOKDD5KhSmJTiZLsjHg&dib_tag=se&keywords=glossy%2Bsilicone%2Bmat&qid=1714391237&sr=8-2&th=1
Wire stripper	$ 8.39	https://www.amazon.com/WGGE-Professional-crimping-Multi-Tool-Multi-Function/dp/B073YG65N2/ref=sxin_15_pa_sp_search_thematic_sspa?content-id=amzn1.sym.c710346c-a6d3-4c17-9da9-4db5b1dcc5b8%3Aamzn1.sym.c710346c-a6d3-4c17-9da9-4db5b1dcc5b8&crid=1PBUNNFM0CYI3&cv_ct_cx=wire+stripper&dib=eyJ2IjoiMSJ9.chiCfO8GtiZdL9bgmweUnLOpYKVYP8O4vgH8w0McDf2yVkTwmjh64368WYbWtSfZyuLkoK08o1GwH51zX_VxKA.YgJIkKlDjwRBqq3WUO-_MCiT1kklJef6ifxhfRMtQTA&dib_tag=se&keywords=wi

		re+stripper&pd_rd_i=B073YG65N2&pd_rd_r=7e152c30-fa42-44ff-ab74-c45f132cbeb9&pd_rd_w=rBrB5&pd_rd_wg=iUWKZ&pf_rd_p=c710346c-a6d3-4c17-9da9-4db5b1dcc5b8&pf_rd_r=4QE365SDMWXR3YMQBZNZ&qid=1714391430&sbo=RZvfv%2F%2FHxDF%2BO5021pAnSA%3D%3D&sprefix=wire+stripper%2Caps%2C127&sr=1-2-22b99f6c-9d79-4634-962b-718698cdc411-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9zZWFyY2hfdGhlbWF0aWM&psc=1
Wire cutter	$ 5.47	https://www.amazon.com/Hakko-CHP-170-Micro-Cutter/dp/B00FZPDG1K/ref=sr_1_4?crid=2T3H28VC8RKJV&dib=eyJ2IjoiMSJ9.8lhSXNfiTKvlAbHTSufvICLoqe73yict45G_hzRZ0n4AVOgz25M8vmUkxOO63zbeIDj1wRfQf87Rocmh1ramyZFxNu-SnLLfIrFCAi-wF7sukMMNUGzpfC2z4YY6gCIUgsWzdTOSWKYiHeYv8UaWxzcuKMJH695-yKmG7BfyREcXxZ9H4R1HtO-CXlBOMnH9-5y0yS8QcJH8SaLcc09Tf0WNQJNgV2n_DqZbpNAaBB7UTCMklnkxF74sZGCQuooHAsqjb97GY43gYMBIAf0QEovZK8DzH5eDcjeEXYGVnZU.5MUiGhYRwSsNQOFPVEJ8sQloQUaPBJ3oLei3py3x9eo&dib_tag=se&keywords=wire+cutter&qid=1714391459&s=hi&sprefix=wire+cutte%2Ctools%2C178&sr=1-4
Tweezers	$ 6.99	https://www.amazon.com/Precision-Anti-Static-Electronics-Sodlering%EF%BC%8CJewelry-Laboratory/dp/B07ZBZ7MSF/ref=sr_1_6?crid=2IHONTMNLRUJJ&dib=eyJ2IjoiMSJ9.QyWYiyro38eCOK7JV2_w0goN4aEUsZc-Me4JB7qL8dqd1rcShF6oXjcaJcKNYv52bZB4L5Xnc9_IWG9HsLKftW82t6ltr_PD_D8qbdCkls05wt7VD5xaIzhkhM5DIPpTzxephGchruuObfr18hkrC9KLEBQ2W2QViEQACJokHdvw41HEkA5MQejdWJDtPhK8AVTcmTfdK1DWg8RdVglJblDWEh2dXNozps0h-ZhQWKb3TD4MMFHEh-JvWfEIwDgQliB31zA4ZoNJBM45GE-YywAVFwSPB4f8r_P3BG1B33I.Cb8fS9QF7fHYHqPtoz27BnBVuVFfIjlyng-WcEsjY_g&dib_tag=se&keywords=anti+static+tweezers+electronics&qid=1714391490&s=hi&sprefix=anti+static+tweezers%2Ctools%2C129&sr=1-6

Instructions

Build the Main Circuit Board

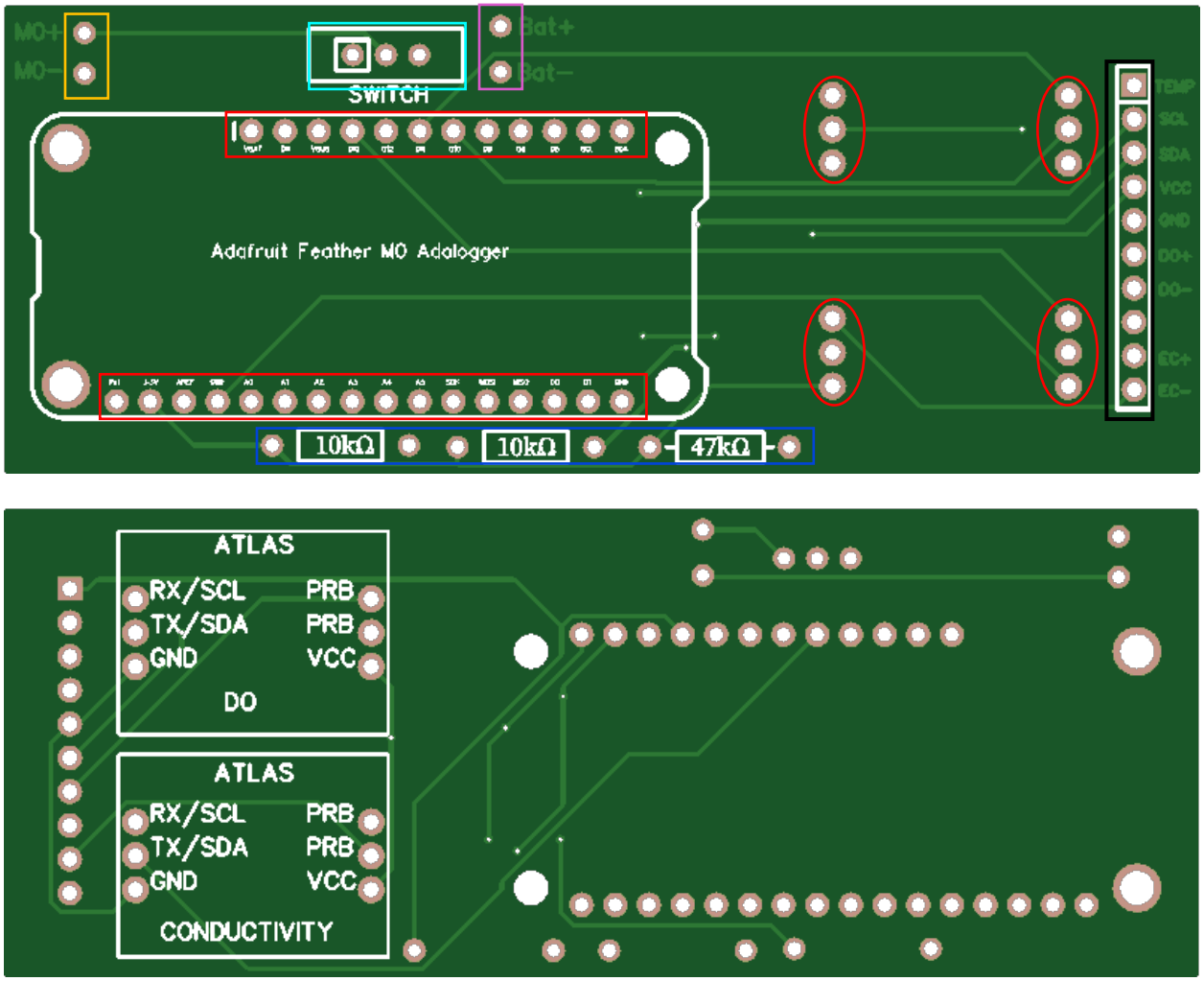

Figure 8. ctdTurbO_2 circuit board. The top image will be called Side A, and the bottom image will be called Side B.

Step 1. Cut female header pins to segments of the following lengths: 1x 12 pins, 1x 16 pins, 4x 3 pins. Solder the 12 pin and 16 pin headers in the holes marked with red rectangles in Figure 8 such that the sockets are on Side A. Solder the 4 pin headers in the holes marked with red ovals in Figure 8 on Side B.

Step 2. Solder 10 kΩ and 47 kΩ resistors in their labeled spots marked in blue in Figure 8 such that the legs are exposed on Side B. Cut off the excess material.

Step 3. 2-pin JST connectors may have red and black on either side. Plug the male connector into the power port in the Adalogger. Check that the red wire is nearer the SD card slot, and the black wire nearer the Micro USB port. If so, proceed to Step 4. If not, unplug the connector, cut the wires close to the plug, and solder them back in opposite locations. Wrap the connections with electrical tape to prevent shorts. If necessary, swap the wires in the female connector and the battery following the same procedure.

Step 4. After checking the polarity of the JST connector, install the male plug by soldering the red wire to M0+ and the black wire to M0- on side A (marked in orange in Figure 8). Solder the red wire of the female plug to Bat+ and the black wire to Bat- on side A (marked in magenta in Figure 8).

Step 5. Install the slide switch on Side A in the location marked in blue in Figure 8.

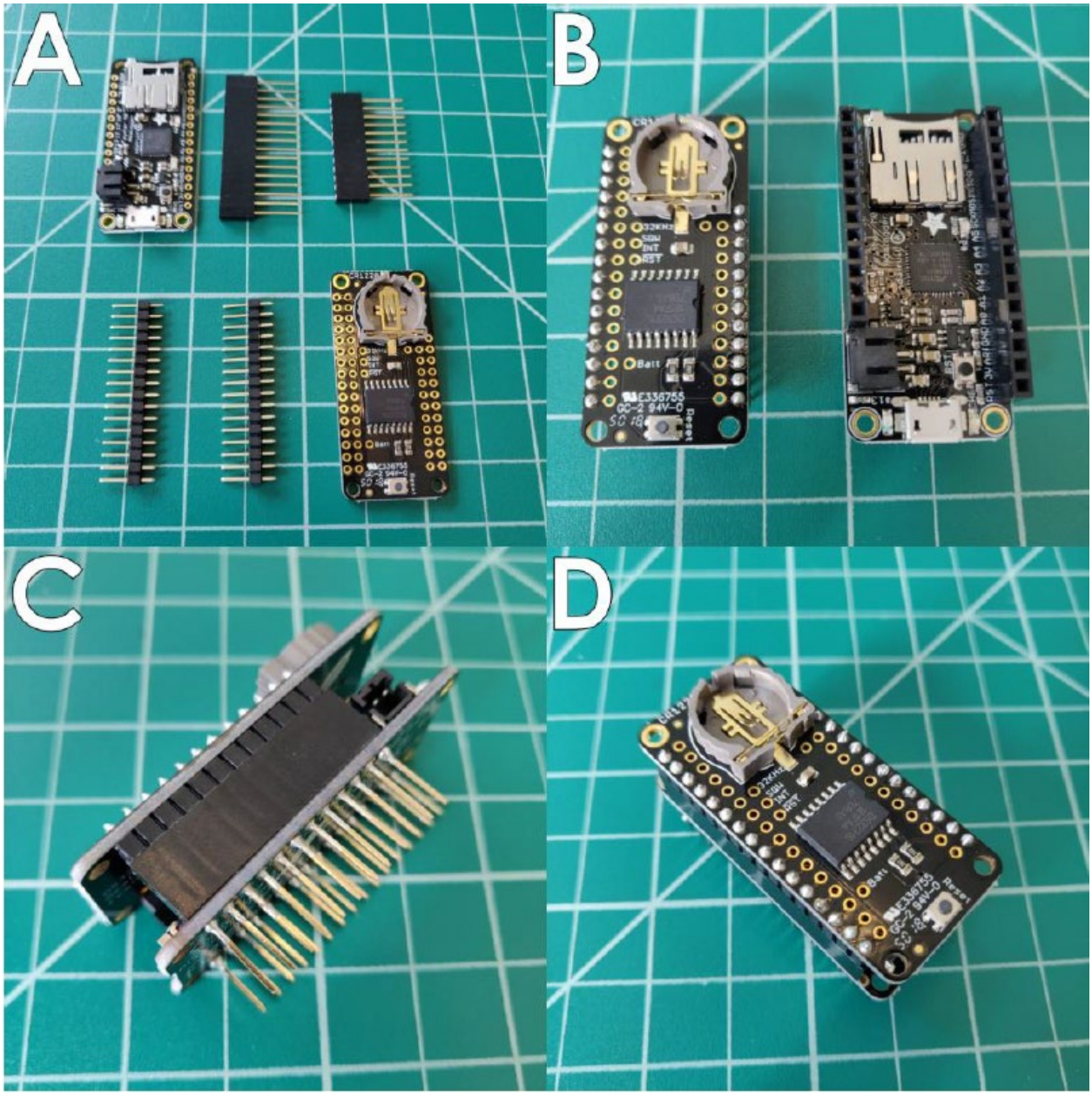

Figure 9. Connecting Adalogger and DS3231 using male and female header pins. A: Adalogger and DS3231 with associated headers. B: After soldering. C: Side view of connected components. D: Top view of connected components (Thaler, et al., n.d.).

Step 6. Solder female header pins to the Adalogger. Solder male header pins to the DS3231 Featherwing as in Figure 9.

Step 7. Insert pins on Adalogger into the headers on the PCB.

Step 8. Insert the Atlas conductivity and oxygen circuits in their marked locations on Side B.

Build the PVC Housing

Step 1. Use a PVC cutter to cut a 30 cm segment of pipe.

Step 2. Use a rotary tool with a cutting wheel to cut a large notch in one end of the pipe. It should be 4 cm deep along the length of the pipe and 7 cm wide around the circumference of the pipe. On the same end cut 3 evenly spaced notches, 4 cm deep and 1 cm wide around the circumference.

Prepare Probes for Casting in Epoxy

Step 1. Cut 2x 6 cm segments of wire in each of the following colors: red, black, blue, and green.

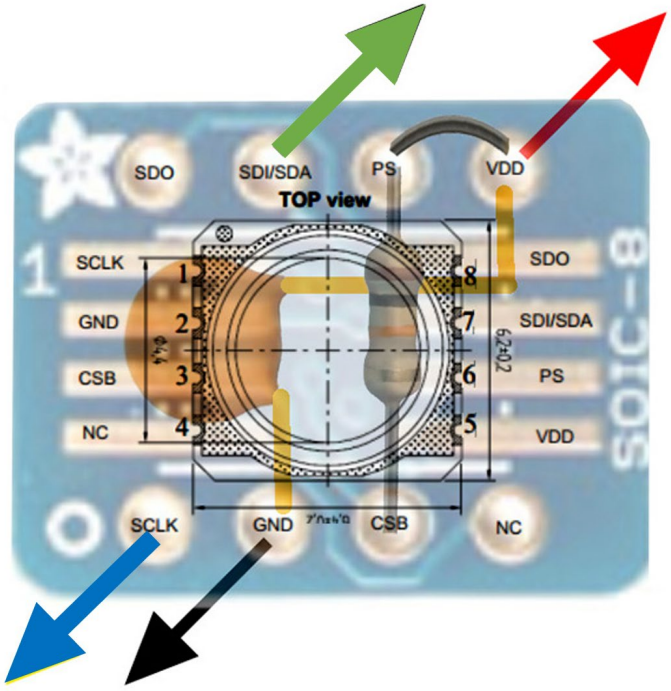

Figure 10. Diagram of pressure sensor chip and component alignment on SOIC-8 DIP adapter. Modified from ("Tutorial: Using an MS5803 Pressure Sensor with Arduino," 2014).

Step 2. Solder the pressure sensor chip to the SOIC-8 to DIP adapter. Check that the dot on the pressure chip is lined up with Pin 1 on the adapter.

Step 3. On the back, insert a 10 kΩ resistor through the PS and CSB holes. Bend the legs to hold the resistor in place, but do not solder. Insert the 100 nF capacitor through the GND and VDD holes. Bend the legs and do not solder. Insert the wires in the holes on the backside of the SOIC-8 DIP adapter in the holes indicated in Figure 10. Solder everything together, while making a solder bridge between the PS and VDD holes. Cut the excess material off the legs of the resistor and capacitor.

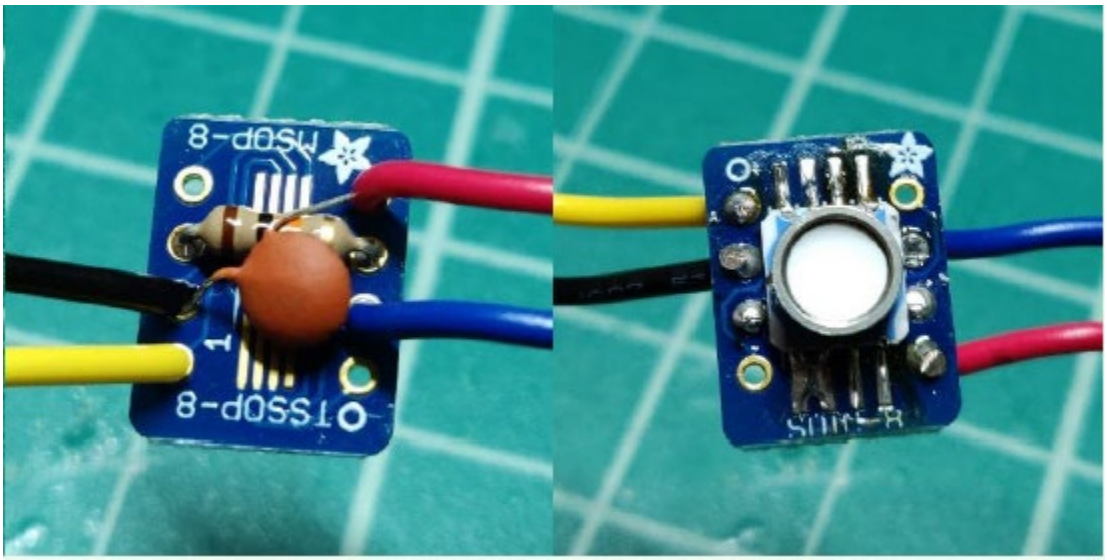

Figure 11. Finished pressure sensor. A: Back. B: Front. (Thaler, et al., n.d.).

Step 4. Solder the remaining black, red, green, and blue wires in the holes GND, VCC, SDA, and SCL holes on the back of the VCNL4010 (backscatter sensor).

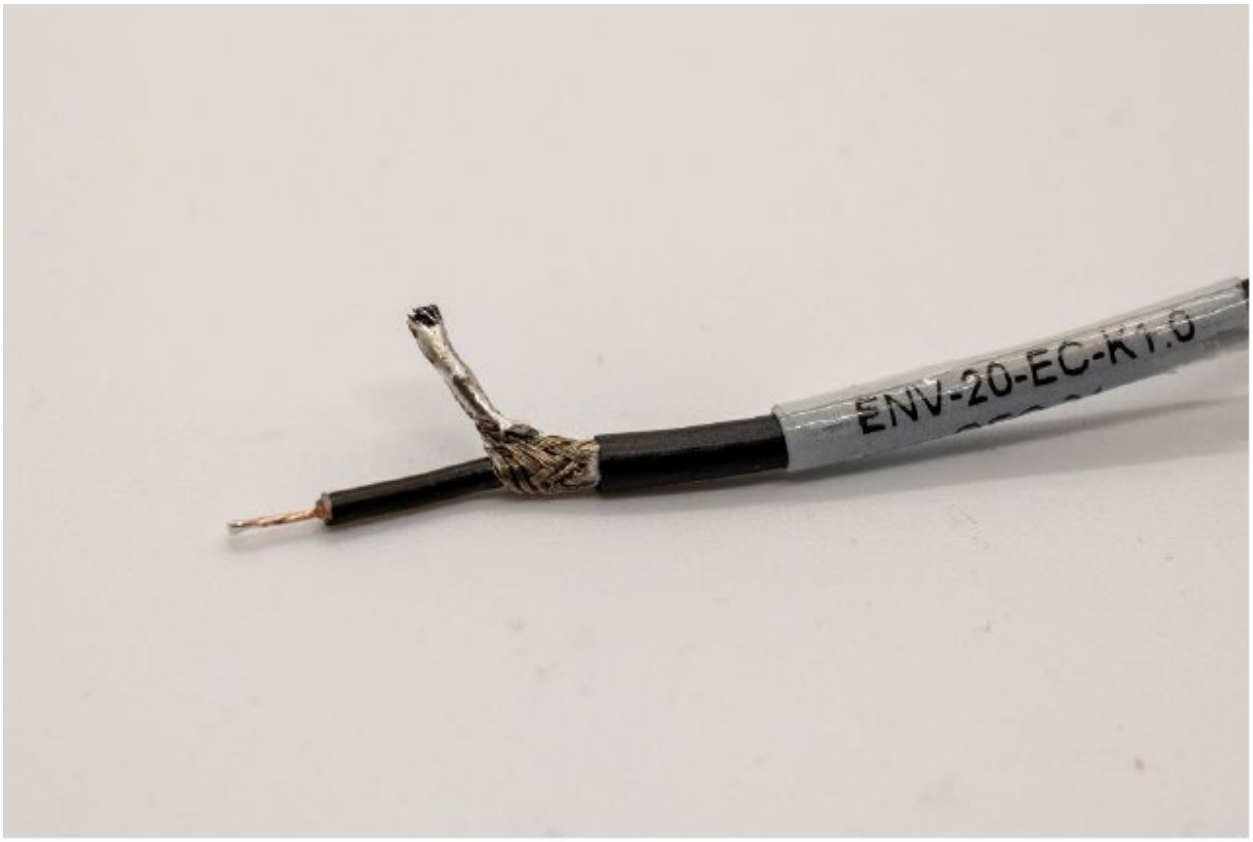

Figure 12. Conductivity and oxygen sensor leads. (Thaler, et al., n.d.).

Step 5. Cut the SMA connector off the conductivity sensor. Strip 2 cm of insulation off the cable. Carefully unravel the braided outer wire and twist together on one side as in Figure 12. Use solder to secure the twist. This will be the negative side of the probe, and the inner wire will be the positive. Repeat with the oxygen sensor.

3D Print and Cast the Endcap

Step 1. 3D print the endcap in black from the *openctdturbo v15.stl* file in the project GitHub.

Step 2. Use kimwipe and isopropyl alcohol to clean the glossy side of silicone mat and endcap. Place endcap face down on glossy side of mat and allow both to dry for 5 minutes.

Step 3. Measure out 6 g VViViD Scientific Epoxy (2 g EPX762 and 4 g EPX 128) per endcap in a paper cup. Stir mixture well with a popsicle stick. Apply heat with a heat gun to remove bubbles. Take care not to inhale fumes. Optional: extract bubbles by placing cup in a vacuum chamber.

Step 4. Use popsicle stick to apply epoxy mixture to the front of the pressure sensor board. Ensure that no epoxy touches the white gel membrane of the pressure sensor. Carefully insert pressure sensor into the pressure sensor hole in the endcap. Pour epoxy over pressure sensor board to fill well.

Step 5. Fill the backscatter sensor well in the endcap halfway with epoxy. Dip the backscatter sensor in epoxy and seat in the backscatter sensor well. Ensure that the view of the black emitter/receiver chip is unobstructed. Fill the well the rest of the way with epoxy. Hold wires up such that the backscatter sensor remains in place during curing.

Step 6. Allow the endcap to cure for 24 hours.

Step 7. Hold endcap using clamps or table vise such that pressure and backscatter sensors point horizontally. Insert conductivity sensor into endcap. Use hot glue on the backside (the part that will not be exposed to the environment) to hold the sensor securely in the endcap. Repeat with dissolved oxygen and temperature sensors.

Step 8. The wires for the backscatter and pressure sensors are not as long as those for conductivity, temperature, and oxygen. Splice red, black, blue, and green wire onto the existing leads so that they roughly equal in length to those for conductivity, temperature, and oxygen (~30 cm). Use heat shrink or electrical tape to prevent shorts. Twist and solder the ends of the blue (SCL) wires of the pressure and backscatter sensors together. Repeat with green (SDA).

Twist and solder the ends of the red (VCC) wires of the pressure, backscatter, and temperature sensors together. Repeat with black (GND).

Step 9. Cover the backscatter and pressure sensors with electrical tape. Ensure that the tape does not actually touch the gel membrane of the pressure sensor.

Step 10. Apply PVC cement to the sides of the endcap and to the inside of the pipe on the side with the sensor guard. Line up the conductivity, temperature, and oxygen sensors so that they are protected by the sensor guard. Slide the endcap into the tube. If necessary, push the end cap in by tapping with a rubber mallet. Allow to cure for 24 hours.

Step 11. Stand the sensor with the sensors pointing down. Pull all the wires out and tape them to the outside of the pipe.

Step 12. Measure out 12 g VViViD Scientific Epoxy (4 g EPX762 and 8 g EPX 128) per ctdTurbO_2 unit in a paper cup. Stir mixture well with a popsicle stick. Pour the entire mixture into the pipe, while taking care to minimize the amount of epoxy mixture that gets on the pipe wall or the wires. Allow to cure for 24 hours.

Step 13. Solder wires into their appropriately labeled holes on the board marked in black in Figure 8.

Programming and Deploying the ctdTurbO_2

Step 1. Download the CTDTURBO GitHub library (found here: https://github.com/whorediddavidgo/ctdTURBO) to your computer. Download and install the Arduino IDE and the following libraries: Wire, RTClib, Adafruit_SleepyDog, SPI, SD, OneWire, DallasTemperature, MS5803_14, SoftwareSerial, and Adafruit_VCNL4010.

Step 2. Use the microUSB cable to connect the Adalogger on the assembled system to your computer. Open the Serial Monitor and set baud rate to 9600. Set *sleepDuration_seconds* to 0 for continuous sampling. For intermittent data collection (recommended to save power in long-term environmental deployments) set *sleepDuration_seconds* to the desired duration between sampling periods in seconds. Set *samples_per_wake* to the desired number of samples per sampling period. Upload the code. If successful, the serial monitor will produce a continuous readout of sensor data. Flip the slide switch on the circuit board to allow the unit to run off battery power and disconnect from the computer. For accurate timekeeping, the code must be reuploaded every time the sensor loses power, e.g. when the sensor is turned off between deployments.

Step 3. For field deployment, remove the wingnut from the pressure fitting and wrap the threads with Teflon tape. Screw the wingnut back on. Push the circuit board into the pipe, insert the removeable cap, and screw it on tight. Wrap the gap between the cap and pipe with electrical tape.

Calibrating the ctdTurbO$_2$

Salinity

Step 1. Fill a 1000 mL beaker with 300 mL deionized water. Turn the sensor on in continuous measurement mode and start a stopwatch at the exact moment of the first measurement. Dip the sensor head in the water and ensure that there are no bubbles caught inside the conductivity probe. Note the time into the test that the sensor goes into and out of the water. Sample data formatted for the R code to produce a calibration curve are provided in *salinity_test_additions_TEMPLATE.csv* in the project GitHub.

Step 2. Weigh out ~2 g aquarium salt and note the exact mass.

Step 3. Dissolve the salt completely in the water. Dip the sensor in the beaker, and note the time into the test that the sensor goes into and out of the water.

Step 4. Repeat steps 2 and 3 until the salinity in the beaker is ~35 ppt.

Step 5. Turn off the sensor using the slide switch. Download the data from the SD card into the same folder as the salt additions file.

Step 6. Set the filenames and file path in *calibrations_markdown.Rmd* to the appropriate values to produce a calibration curve as in Figure 13.

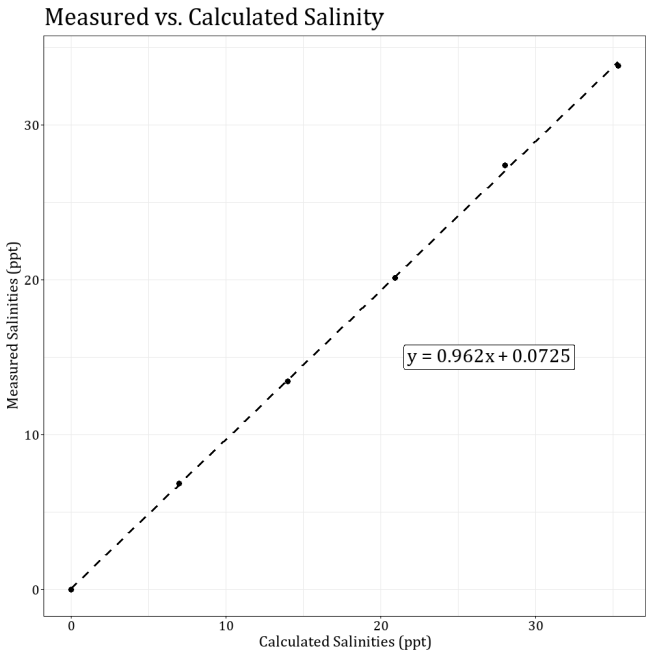

Figure 13. Salinity calibration curve.

Turbidity/Suspended Sediment Concentration

Note: this method was not able to produce an accurate calibration curve. Further work is needed to reduce the return from the bucket walls. Other calibrations with natural sediment include up to

100x greater suspended sediment concentrations (Eidam, et al., 2021). An alternative method is included in the OpenOBS Build Guide, linked in the project GitHub.

Step 1. Fill a basin with enough water such that when the sensor head is dipped in, it is at least 30 cm away from the walls and floor of the basin. Calculate the exact volume of water by filling the basin from a hose with a known volume flow rate and timing the filling. Turn the sensor on in continuous measurement mode and start a stopwatch at the exact moment of the first measurement. Dip the sensor head in the water. Note the time into the test that the sensor goes into and out of the water. Sample data formatted for the R code to produce a calibration curve are provided in *turbidity_test_points_TEMPLATE.csv* in the project GitHub.

Step 2. Measure out ~3-5 g silt (< 63 μm) and note the exact mass. Fine material is preferable because it remains in suspension longer than coarse material.

Step 3. Pour the sediment into the basin. Stir the basin vigorously to get the material in suspension and dip the sensor in for 10-30 seconds. Note the elapsed time into the test that the sensor goes into and out of the water.

Step 4. Repeat steps 2 and 3 until estimated suspended sediment concentration is ~400 mg/L and the water appears visibly cloudy to the eye.

Step 5. Turn off the sensor using the slide switch. Download the test data from the SD card to the same folder as the sediment additions file.

Step 6. Set the filenames and file path in *calibrations_markdown.Rmd* to the appropriate values to produce a calibration curve as in Figure 14.

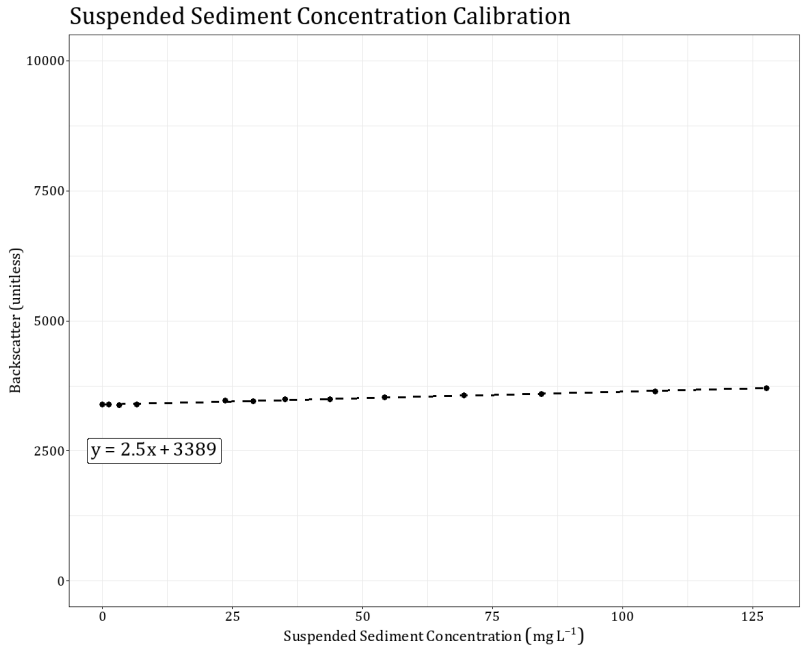

Figure 14. Suspended sediment concentration calibration curve. There is a high backscatter return even at low concentrations because emitted light reflects off the walls and floor of the basin.

Dissolved Oxygen

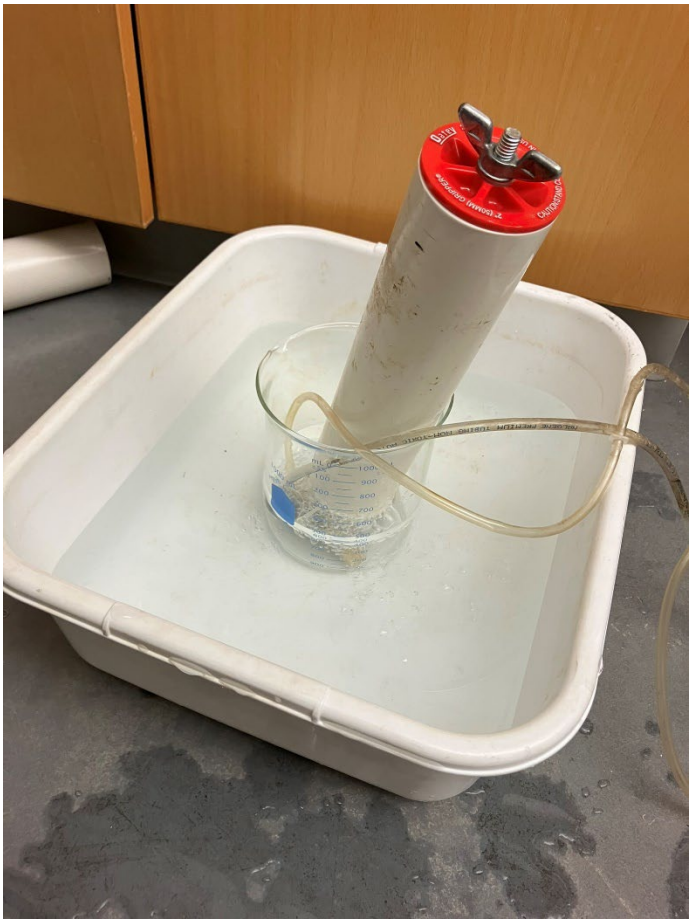

Figure 15. Dissolved oxygen calibration experimental setup.

Step 1. Fill a 1000 mL beaker with 300 mL deionized water. Use an aquarium bubbler to aerate the water.

Step 2. Fill a larger, shallow bin with ice and water. Set the beaker with deionized water and bubbler in the bin and wait at least 30 minutes to allow the temperature to equilibrate and oxygen concentration to reach saturation.

Step 3. Turn the sensor on in continuous measurement mode and set it in the beaker. Leave the sensor until the ice melts. This may take up to 12 hours.

Step 4. Load the test data onto the computer. Change the file path and filename in *calibrations_markdown_Rmd* to the appropriate values to visualize the relationship between temperature, oxygen concentration at saturation, and measured oxygen concentration as in Figure 16.

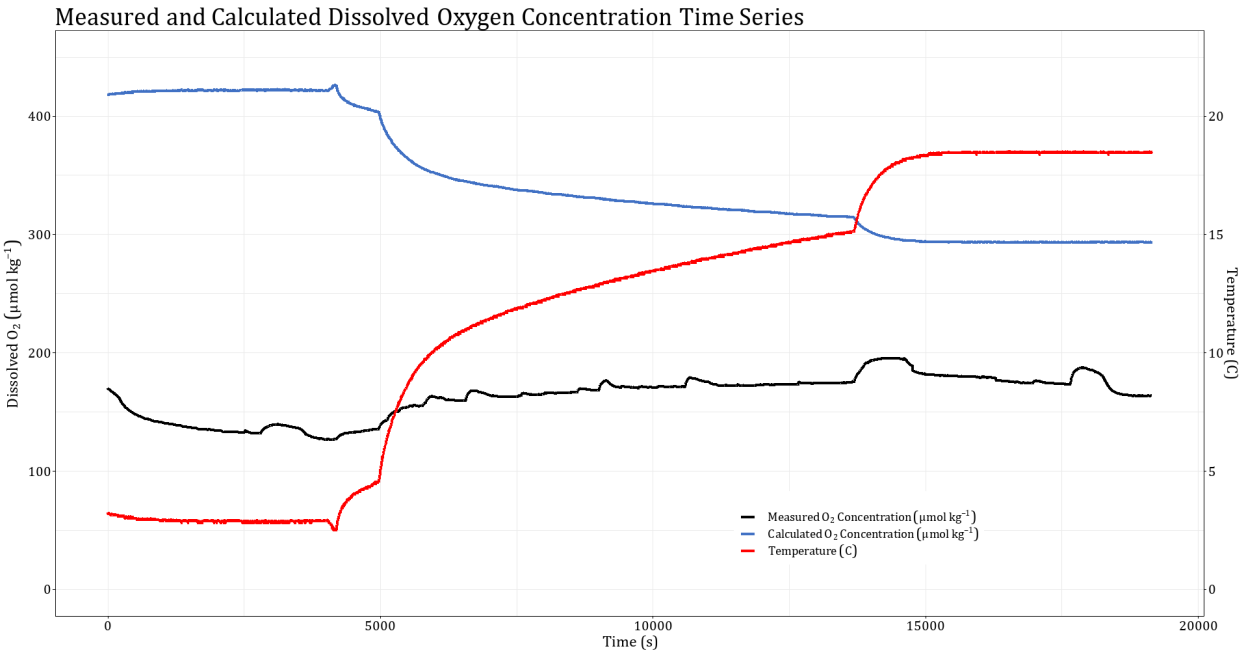

Figure 16. Dissolved oxygen calibration curve. This test was conducted after the sensor membrane was damaged.

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