Wi-Fi enabled CTDs in Citizen Science

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Monitoring the vast expanse of oceans presents a daunting challenge: how to take sufficient high-quality measurements with a relatively small group of specialized scientists and limited resources. Despite advances in remote sensing and autonomous technology, the oceans remain under-explored and under-sampled. One solution for addressing this challenge is to rely on citizen scientists, people outside of the scientific community, to collect oceanographic data.

This paper describes how through three unique successful citizen science programs, oceanographers have increased temporal and spatial coverage of high-quality CTD profiles using a Wi-Fi enabled CTD and an easy to use mobile device app. The three programs include the Shelf Research Fleet: a group of fishermen partnered with Woods Hole Oceanographic Institute, the Pacific Salmon Foundation: a partnership between the Department of Fisheries and Oceans Canada and Ocean Networks Canada, and the Coastal Community Ocean Observers program: a network of citizen scientists distributed along remote Alaskan coasts.

Keywords—CTD; Wi-Fi; wireless communications; real-time data; conductivity; salinity; temperature; profile; citizen science

I. Introduction

Aptly nicknamed the Blue Planet, more than seventy percent of the Earth is covered by oceans. This vast expanse of water presents a daunting challenge: namely, how to take sufficient measurements with a relatively small group of specialized scientists and limited resources.

Despite advances in remote sensing and autonomous technology (e.g., drifters, gliders, AUVs, ASVs, profiling floats, etc.), which helps us collect more data now than ever before, the oceans remain under-explored and under-sampled. High-resolution models of small-scale processes and the necessity for continuous time series covering climate-scale changes are examples that make evident the vast amount of data required by oceanographers. One solution for overcoming this challenge is to rely on people outside of the scientific community for collecting oceanographic data, known as citizen scientists.

Oceanography as a formal scientific discipline is relatively young, but its history is ripe with "citizen scientists," including Charles Darwin and Benjamin Franklin. These early citizen scientists were influential in defining some of the fundamental principles in oceanography and increasing public awareness of the importance of our oceans [1]. As the discipline of oceanography matured, so did the observational techniques, and the instruments used by oceanographers increased in complexity, accuracy and precision [2]. In particular, the conductivity, temperature and depth logger (CTD) grew into a primary tool for determining essential physical properties of the oceans, such as salinity. However, the complexity of the instrument required users to have specialized training in its operation, programming, and deployment techniques.

Modern technology has allowed the CTD to evolve into more compact and easier to use packages. Here we will describe how three successful citizen science programs are assisting oceanographers to increase temporal and spatial coverage of high-quality CTD profiles with a Wi-Fi enabled CTD and a user-friendly mobile device app. Citizen science programs using this technology range from commercial fishing operations to remote Arctic residential communities deploying near the coast and through ice holes. In many cases, the data collected is directly useable by the observer and therefore, the relationship between citizen and scientist is synergistic.

II. Methods

Defined by the needs of an individual program, citizen-driven field operations may have more or less stringent data quality requirements. In the examples provided hereafter, the program managers are interested in oceanographic research quality data. These programs also require the instrumentation to be user-friendly and deployable with only minimal training. For these purposes, the RBR loggers discussed below were selected.

A. CTD Instrumentation

There are many CTD products on the market that are available for research and citizen science projects. The projects described in this paper are all using the RBR*concerto* CTD, a compact low-powered CTD manufactured by RBR Ltd., which logs data internally and is equipped with three high accuracy sensors; conductivity (±0.003 mS/cm), temperature (±0.002 C), and pressure (i.e. depth, ±0.05% FS) (Figure 1). The RBR*concerto* also has the ability to integrate up to two additional auxiliary sensors, such as dissolved oxygen, fluorometers, turbidity sensors, or PAR. All sensor calibrations and parameter conversions are stored and utilized onboard the instrument, which then provides outputs in engineering units.

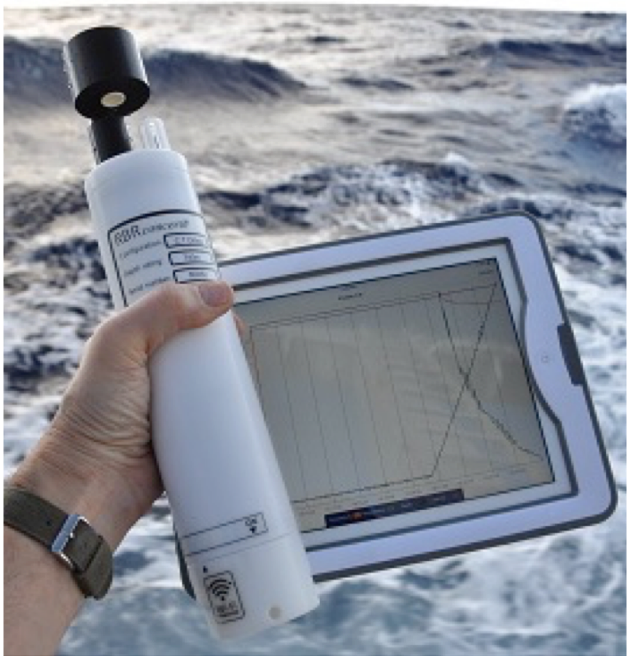

Figure 1. A RBR*concerto* CTD and tablet dispaying data collected by the logger. The Wi-Fi module is internal to the logger. Sampling and powering the Wi-Fi module can be activated by twisting the loggers end cap.

The data file is based on the SQLite database format, which is easily imported into post-processing software. Additionally, RBR has compiled RSKtools, a Matlab toolbox to assist with data importation and common CTD post-processing procedures.

For profiling applications, such as those in the example programs below, the RBR*concerto* CTD samples at rates up to 12Hz. Coupled with CTD sensor time constants of 100ms or better, this provides excellent vertical resolution and is somewhat forgiving in terms of profiling speed for less formally trained deployment personnel, which we will address further later in this paper. Deployment battery endurance is generally a function of the sensors integrated onto the CTD, with most configurations allowing for many days of high sample rate data collection.

B. Wi-Fi Communications

The RBR*concerto* CTD can be equipped with a Wi-Fi module and twist-activated end cap to enable wireless communication. Wireless communication is compatible with Ruskin, RBR's multi-platform software available for PC, Mac, iOS, and Android.

The mobile versions of Ruskin are what the citizen scientists are most likely to use, and is favored because of the simple and familiar interface. The desktop version of Ruskin allows all the same functionality as if the CTD were connected via a cable, and is most often used by a chief scientist who initially programs the instrument for use.

The Wi-Fi module can be activated/deactivated by a few methods. Twisting the battery end cap to either the on or off position will start the Wi-Fi module. On and off simply refer to the sampling state of the logger (i.e. actively sampling or paused). Once broadcasting, the user can connect to the logger using its unique SSID. If no connection is made within a timeout threshold (default = 60s), the module will time out and shut down to save power.

If deployed while still connected to the logger, the Wi-Fi module will automatically shut off once deeper than 1m. Since Wi-Fi does not work through water, there is no need to power the unit while actively profiling. Furthermore, the Wi-Fi module will automatically re-activate when it once again becomes shallower than 2m (Figure 2). This allows the user to connect to the logger without having to physically touch the unit, proving useful in A-frame/davit style deployments and when the sea-state is rough.

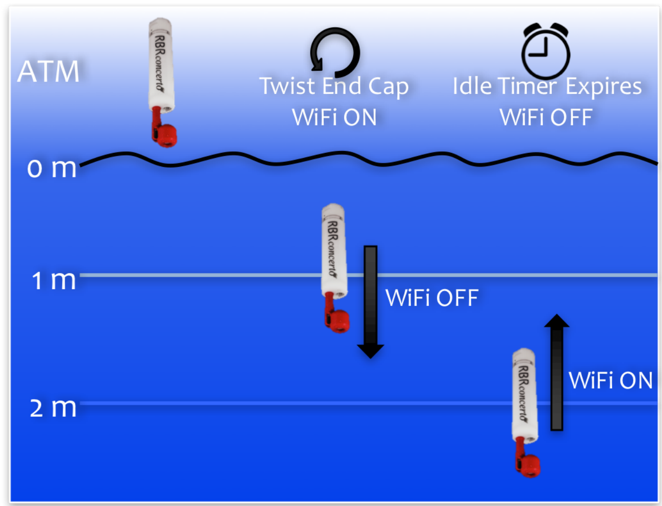

Figure 2. The Wi-Fi module can manually be activated by twisting the end cap. Automatic control deactivates the module by timing out or by being deployed to a depth greater than 1 meter. In the latter case, the module will be re-activated when returning to a depth of 2 meters.

Once connected to the logger via a mobile device, data are synced automatically. Early on, user feedback has proven that geolocation information would be critical in determining where the profile had been collected. Therefore, recent versions of mobile Ruskin also insert a GPS coordinate from the mobile device's location services into the data file. Updated geolocation info is saved during each data sync, which typically follows a profile. Data is then immediately viewable by the user and can be archived and telemetered to a location accessible by the scientists.

C. Training the Citizen Scientists

A crucial component to a successful citizen science program is the ability to collect useful data and maintain the equipment. The programs introduced here do that with periodic interaction between the scientists and citizens which not only provides the equipment training, but also a feedback mechanism for the citizens to share their local knowledge of the working areas and to have an impact on the science planning process.

These programs all use a similar training model. A principal investigator or other scientific representative from the program receives initial detailed training and understanding of the equipment from the manufacturer. With this and unique project nuances in mind, an informed trainer designs the protocol that they would like their volunteers to follow. Common aspects of training a citizen scientist to use a RBR*concerto* CTD include introductions into enabling and pausing data acquisition, proper profiling techniques, mobile device use, and in some cases battery replacement.

For example, a trainer will start by explaining what a CTD is and why it's used. They then share that the CTD has been preconfigured and sampling is enabled/paused by a twist of the end cap, resulting in a physical cue (vibration) from the logger to alert the user that the state has changed. Then, proper profiling techniques are introduced, which includes covering ideal profiling speeds, importance of keeping the logger orientated vertical, ensuring the sensors remain unobstructed, and how to work with large differences in air-sea temperatures. This is followed by an introduction to app use for obtaining data from the logger, viewing the data, and transmitting the data to the science database. For the citizen scientist, this is where the process ends; however, the raw CTD data then undergoes QA/QC checks and data processing by the scientific team. It is then archived and made available via the internet and/or through reports.

III. Three Successful Citizen Science Programs

Three examples of citizen science programs currently utilizing the Wi-Fi enabled CTDs are introduced here. Each of these programs are managed by scientists and/or a scientific institution; however, the data are collected via a broad range of volunteers that are already frequenting the study area. This approach helps maintain data quality while also minimizing the operating costs of the program.

A. *Shelf Research Fleet*

In 2014, Commercial Fisheries Research Foundation (CFRF), in partnership with scientists at the Woods Hole Oceanographic Institution (WHOI), successfully launched the Shelf Research Fleet: a group of fishermen who deploy CTDs from their vessels on a weekly basis, collecting vertical profiles of temperature and salinity from designated zones across the continental shelf and slope south of Rhode Island (Figure 3). The data they obtain is immediately available for viewing onboard the fishing vessel using tablets, which displays valuable temperature and salinity profiles, useful in deciding where to fish. Participating fishermen have an opportunity to attend workshops with WHOI scientists to share their on-the-water observations about fish movements and oceanographic conditions in the study area, discuss the data collected, and help interpret the results. WHOI scientists have used the 373 profiles (as of July 5th, 2017) collected to determine seasonal transitions and stratification patterns and assess the frequency, timing, and extent of onshore penetration of warm, saline intrusions of slope and Gulf Stream waters onto the continental shelf.

This partnership has generated significant media interest, including multiple newspaper and magazine articles. In addition, a documentary on the Gulf Stream was aired in Germany and France in April 2017 that highlighted the use of the CTD and showed both fishermen and scientists discussing recent changes in oceanographic conditions revealed by the data collected by the Shelf Research Fleet.

Data, presentations, outreach efforts, and additional project information can be accessed on the official website of the Shelf Research Fleet [3].

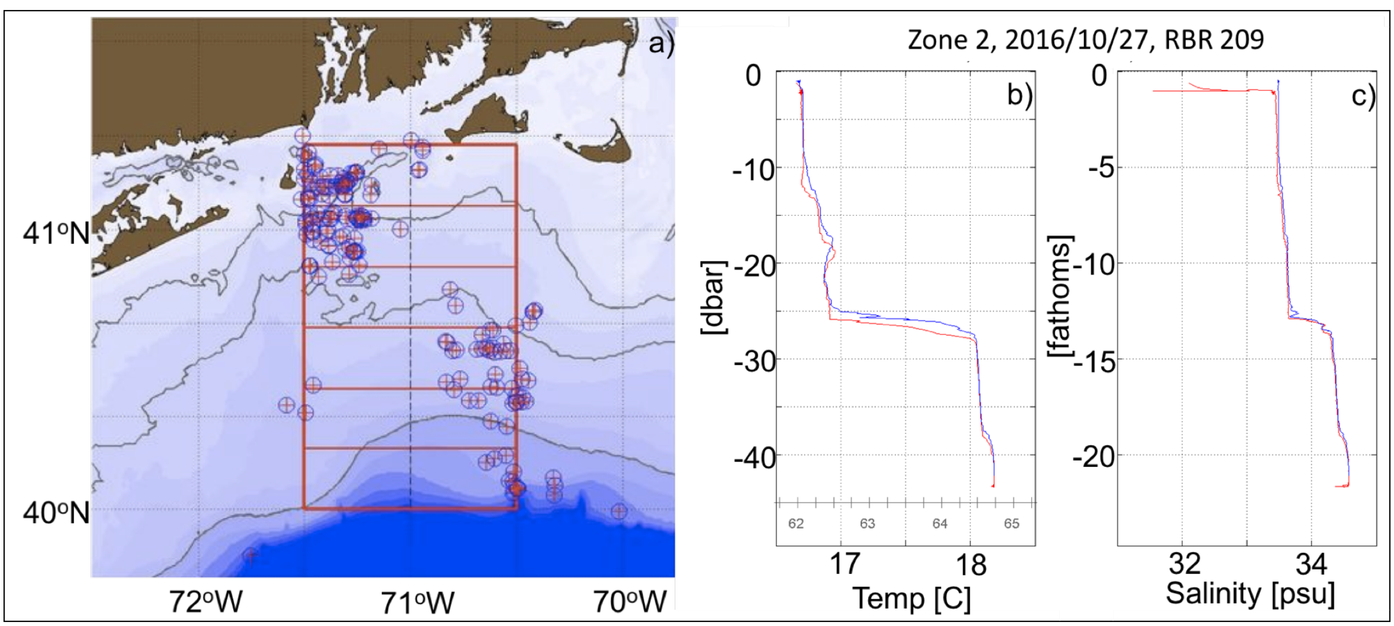

Figure 3. The Shelf Research Fleet has collected 373 profiles as of July 5th, 2017 from 6 zones south of Rhode Island. a) A map of the project area highlighting zone and profiled locations, 1 being the most Northward. Plots b) and c) display representative data from a single profile collected on Oct 27, 2016 in Zone 2. Temperature and salinity are plotted respectively and vs depth.

B. Salish Sea Marine Survival Project

Similarly, the Pacific Salmon Foundation (PSF), in partnership with the Department of Fisheries and Oceans Canada (DFO) and Ocean Networks Canada (ONC), has engaged citizen scientists to collect CTD profiles, and other measurements, throughout the Strait of Georgia, as part of the Salish Sea Marine Survival Project (SSMSP). The SSMSP is working to understand the decline of salmon in the region, and involves over thirty projects that investigate many of the physical, chemical and biological processes that affect salmon viability. The CTD, along with integrated dissolved oxygen and chlorophyll data will elucidate the background oceanographic conditions in which the other SSMSP studies take place.

As a result, over 4,000 profiles were collected between February of 2015 and mid-June 2017. Data were collected simultaneously by 7 to 10 different citizen science patrols in various regions of the Strait of Georgia. Patrols typically operate between February and October, and are on the water one to three times monthly. The simultaneous data collection allows scientists at ONC to generate data products such as near surface temperature maps for each sample day (Figure 4).

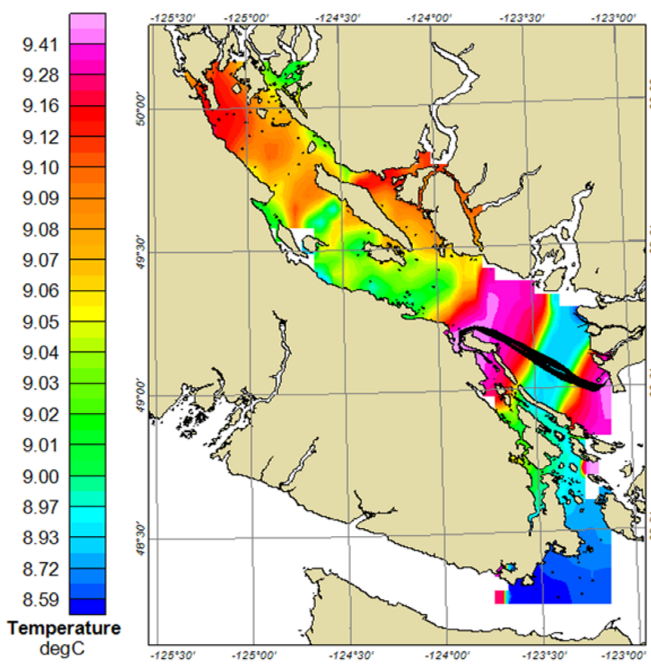

Figure 4. The Salish Sea Marine Surival Project citizen scientists collect data in the Strait of Georgia from multiple sites within 9 sample areas. Near surface temperatures from the CTDs are used to generate temperature maps of the Strait. Displayed here is a representative one-day map from 2015.

As a notable deviation from the other programs discussed here, the SSMSP utilizes an ONC created mobile app called "Community Fishers." This unique app was developed to facilitate data transfer to ONC's "Oceans 2.0" database and data management system. It was specifically designed to be less capable and less instrument specific than the RBR Ruskin app, allowing for future developments to also manage and connect to other instrumentation sets, such as meteorological stations.

Additional information about the other SSMSP studies being conducted, publications of results, technical reports, and meeting summaries can be found on the Salish Sea Marine Survival Project website [4]. Complimentary research information and data from this program are available on the Ocean Networks Canada "Oceans 2.0" data management system [5].

C. Coastal Community Ocean Observers

The Coastal Community Ocean Observers (C2O2) program, started in mid-2014 and funded by the North Pacific Research Board, is a network of citizen scientists currently operating in five remote communities along Alaskan coasts from the high Arctic to southeast Alaska. These areas are of particular interest because they are at the forefront of a changing climate and have remained under-sampled due to limited boat or ship access. For example, the profile time series shown in Figure 5 is the first data set to capture the annual cycle of temperature and salinity from Old Harbor, a remote part of Kodiak Island, AK. The CTD and integrated chlorophyll data collected has provided a baseline for describing and understanding current nearshore ecosystem conditions and changes that are occurring, and opens the door to community involvement in scientific research. Ultimately, the data collected is coupled with other regional information and used as a basis for adaptive management strategies.

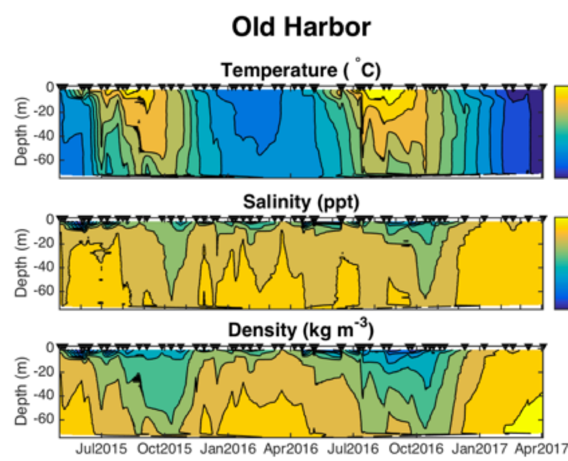

Figure 5. CTD depth vs time plots from Old Harbor on Kodiak Island, Alaska. Triangles show dates of CTD data profiles. This CTD data set is the first such profile time series to captures the annual cycle of temperature and salinity from this part of Kodiak Island. Data were collected by C2O2 observer Glen Clough of Old Harbor.

Additional information, including a data access portal, can be found on the University of Alaska Fairbanks C2O2 website [6].

IV. Conclusion

The citizen science programs discussed here are excellent models for other oceanographic startup programs looking to increase temporal and spatial data coverage while making data collection more cost effective. Engagement with the community has been a key effort in building excitement in the communities involved and in recruiting competent volunteers. Providing training opportunities, holding community forums, discussing data in the local public school classrooms, sharing local knowledge, and reporting study findings are all necessities in maintaining program momentum and data quality.

Likewise, the instrumentation chosen for such programs are a key component in building a successful and credible program. The Wi-Fi enabled CTD highlighted in this paper, the RBR*concerto* CTD, is one example of how complex scientific instrumentation is evolving into more user-friendly packages without sacrificing the quality of the measurement. This CTD delivers high quality data and is compact, lightweight, and easy to use. The use of a familiar mobile device for downloading and previewing data has also proved successful in terms of usability and offering instant feedback in the form of a data plot. For example, the fisherman in the Shelf Research Fleet not only get a visual confirmation that they've collected a proper CTD profile, but also actively use the temperature and salinity data to enhance their fishing efforts.

As the collaboration between industry, academia, and local communities continue to evolve, so will the development of the tools and resources. The inclusion of geolocation logging via the mobile application discussed, was a direct result of industry responding to feedback presented by citizens and scientists using the equipment in the field. Currently, several other user requests have driven developments that are in progress, including an updated mobile application interface designed to introduce customizable data archiving options, enhanced data visualization, and to ensure accurate geolocation tagging.

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