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DATA REPORT
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The 2017 Mission Arctic Citizen Science Sailing Expedition Conductivity, Temperature, and Depth Profiles in Western Greenland and Baffin Bay

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1. INTRODUCTION

The density of polar waters is controlled by salinity, making them so-called "beta oceans" (Carmack, 2007). Changes in salinity, therefore, can alter stratification, which impacts of a host of physical and biogeochemical processes in beta oceans (Carmack, 2007; Brown et al., 2020). Mass loss from the Greenland Ice Sheet has increased by a factor of six since the 1980s (Mouginot et al., 2019) and freshwater runoff into adjacent fjord and shelf waters has subsequently increased (Sejr et al., 2017; Boone et al., 2018; Moon et al., 2018; Mankoff et al., 2020). The increase in freshwater discharge impacts marine ecosystems (Meire et al., 2017; Cape et al., 2019; Seifert et al., 2019; Hopwood et al., 2020; Oliver et al., 2020), and density stratification and circulation in fjords and Baffin Bay (Castro de la Guardia et al., 2015; Sejr et al., 2017; Boone et al., 2018; Moon et al., 2018; Monteban et al., 2020; Rysgaard et al., 2020). The contribution of freshwater runoff from the Greenland Ice Sheet to the freshening observed in the North Atlantic remains an area of active research that relies heavily on numerical ocean models (Liu et al., 2018; Dukhovskoy et al., 2019; Zhang et al., 2021). Synoptic hydrographic observations can aid in quantifying the magnitude and spatial distribution of glacial meltwater in fjord and ocean waters around Greenland to provide much-needed benchmarks for ocean models that attempt to simulate the effects of this added freshwater on ocean circulation, heat transport, and climate (Gillard et al., 2016; Little et al., 2016; Dukhovskoy et al., 2019).

Observations in remote and harsh Arctic environments can be difficult and costly. Additionally, the number of research vessels that operate in Greenlandic waters are limited and are highly sought after. Sailboats have been used as measurement platforms in the region (Miller et al., 1995; Karnovsky et al., 2010; Johannessen et al., 2011; Fenty et al., 2016; Nicoli et al., 2018; Aliani et al., 2020; Bouchard et al., 2020) and marine monitoring programs should leverage the increase in Arctic tourism aboard cruise ships and private yachts (Dawson, 2019; Leoni, 2019; Palma et al., 2019) to increase the spatiotemporal coverage of ocean observations in Greenlandic waters. While sailboats lack the resources of dedicated research vessels, they are small, maneuverable, and flexible, and therefore, are well-suited for citizen science (Simoniello et al., 2019).

Here, we present a pilot project that demonstrated the ability of citizen scientists aboard a sailboat to independently acquire hydrographic data in remote marine environments that are impacted by glacial runoff. The Mission Arctic citizen science sailing expedition collected profiles of temperature and salinity from July to September 2017 in the upper ∼60 m of the water column in western Greenland, Nares Strait, and Baffin Bay (**Figure 1**). This report describes the expedition, hydrographic data collection and quality control procedures, the final data set, and presents preliminary results.

2. METHODS

2.1. Expedition Summary

The Mission Arctic Science Sailing Expedition to western Greenland and Baffin Bay took place aboard the sailboat *Exiles* in summer 2017. *Exiles* departed St. John's Newfoundland, bound for southern Greenland, in late June 2017. *Exiles*' route can be traced in **Figure 1** following a counter-clockwise path from Paamiut in southwest Greenland, north along the west coast of Greenland, and back south along the Canadian Arctic. Scientific activities were coordinated by Dr. Daniel Carlson from the Arctic Research Centre at Aarhus University in Denmark. Dr. Carlson met *Exiles* in Paamiut and disembarked in Upernavik, in northwest Greenland. During July 2017, the Mission Arctic crew conducted conductivity/temperature/depth (CTD) surveys (see section 2.2) of fjords in contact with the Greenland Ice Sheet, acquired low-altitude aerial imagery of coastal macroalgal beds, and recovered moored instruments. Here, we focus on the CTD observations.

After Dr. Carlson disembarked in Upernavik in late July *Exiles* continued north, through Melville Bay and into Nares Strait. *Exiles* proceeded as far north as possible, reaching 80°N, until sea ice forced the vessel to turn around. *Exiles* then turned southwest, following the coast of Ellesmere Island to Craig Harbor and Grise Fjord. *Exiles* sailed southward along the western boundary of Baffin Bay, with stops in Pond Inlet and Clyde Harbor on Baffin Island. *Exiles* returned to Newfoundland in late September, completing a circuit of Baffin Bay, collecting 98 CTD profiles on this leg. In total, 147 CTD profiles were collected during the 2017 Mission Arctic Citizen Science Sailing Expedition. The CTD profiles are described here and they are available for download from the Greenland Marine Ecosystem community data repository on Zenodo (https://zenodo.org/record/4597385#.YF2cPF1Ki8U). The Greenland Marine Ecosystem community data repository (https://zenodo.org/communities/greenmardata/) is a curated repository for relevant datasets collected by professional and citizen scientists. The repository also contains other datasets that were collected during the expedition as well as datasets from other research cruises. A daily summary of activities aboard *Exiles* during July 2017, as well as plots of each fjord transect, are provided with the dataset.

2.2. CTD Profiles

A RBR Concerto CTD (https://rbr-global.com/) that measured conductivity, temperature, and pressure was used in fjords from Paamiut to Upernavik in July 2017. A Sontek CastAway CTD (https://www.sontek.com/castaway-ctd) was used for all stations north of Upernavik in western Greenland and on the return leg along the western shore of Baffin Bay to St. John's, Newfoundland (**Figure 1**). The CastAway features a built-in GPS and liquid crystal display (LCD) screen, and Bluetooth data transfer, which make it relatively easy to use in citizen science field campaigns. The built-in GPS minimizes record-keeping requirements and the LCD screen allows the operator to verify that the instrument is functioning properly, both before and after each profile and the wireless Bluetooth data transfer reduces the risk of flooding the pressure housing when connecting data transfer cables. The CastAway CTD has a maximum operating depth of 100 m, records data at 4 Hz, and has accuracies of ±0.05°C, ±0.1 psu, and 0.25%, for temperature, salinity, and depth, respectively.

2.3. CTD Data Processing

All CTD profiles were quality controlled, binned, and stored in a single network common data form (netCDF; https://www.unidata.ucar.edu/software/netcdf/) file using a template provided by the National Oceanographic and Atmospheric Administration's National Centers for Environmental Information (https://www.nodc.noaa.gov/data/formats/netcdf/v2.0/). NetCDF provides self-describing data in a format that is compatible with popular analysis tools like Ocean Data View, Python, Matlab, and R-Studio.

The raw CTD measurements were processed to remove the surface soak (e.g., a period of several minutes that allows the sensors to acclimate to the ambient water temperature) and the upward segment of the profile. The downcast conductivity data were de-spiked and the conductivity, temperature, and pressure data were used to compute salinity, depth, density, potential temperature, conservative temperature, and potential density. Salinity, density, potential density, potential temperature, and conservative temperature were computed using the Gibbs Seawater Oceanographic Toolbox for Matlab (McDougall et al., 2012).

3. PRELIMINARY ANALYSIS

The CastAway CTD profiles that were acquired by the crew of *Exiles* in August and September 2017 were used to compute the freshwater content (FWC) of the upper 40 m. This depth limit was selected as the glacial meltwater signal is thought to be confined to the upper 30 m (Castro de la Guardia et al., 2015). The FWC was computed following de Steur et al. (2009),

$$FWC = \sum_{z=-40}^{z=0} \frac{S_{ref} - S(z)}{S_{ref}} \Delta z \tag{1}$$

where S_{ref} and $S(z)$ are a reference salinity and a given depth profile of observed salinity, respectively. The reference salinity was computed using a Bootstrap resampling of the mean salinity (Efron and Tibshirani, 1986) at 40 m depth in Melville Bay ($S_{ref} = 33.25$), Nares Strait ($S_{ref} = 31.54$), and off Ellesmere ($S_{ref} = 31.91$) and Baffin Islands ($S_{ref} = 31.51$). The estimates of FWC in the region during August and September 2017 are shown in **Figure 2**. **Figure 2** reveals FWC of ∼2–3 m near the outlets of fjord systems in western Greenland and Ellesmere and Baffin Islands. The FWC in Nares Strait ranged from 1–2 m. Thus, these

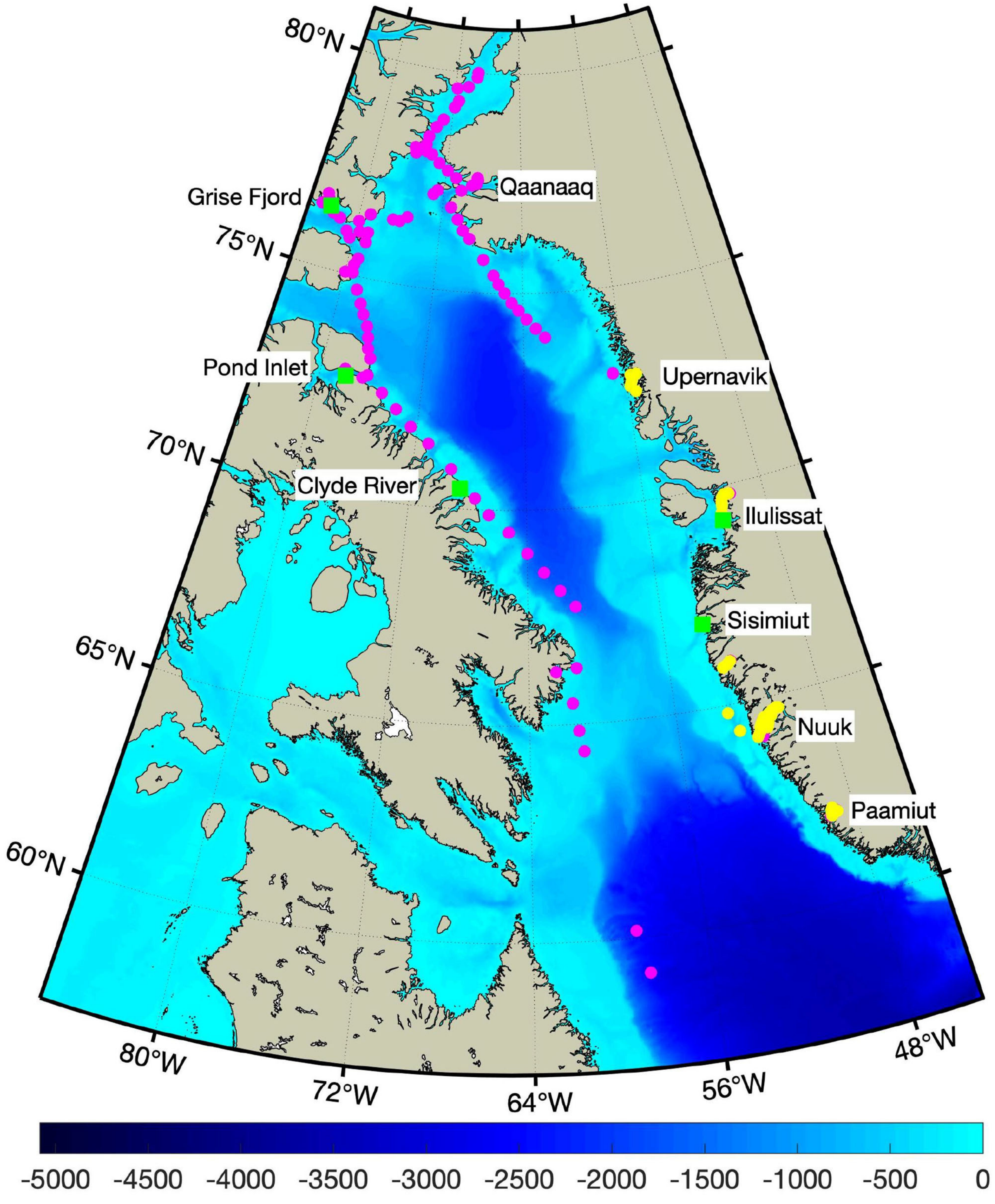

FIGURE 1 | A map of Baffin Bay and the Labrador Sea, bordered by Greenland on the east and Canada to the west. Circles are used to indicate CTD profile locations colored to represent the instrument that was used. Yellow circles correspond to the RBR Concerto and pink circles correspond to the Sontek CastAway. Colored contours indicate ocean bathymetry (meters below sea level) derived from ETOPO1 (NOAA National Geophysical Data Center, 2008).

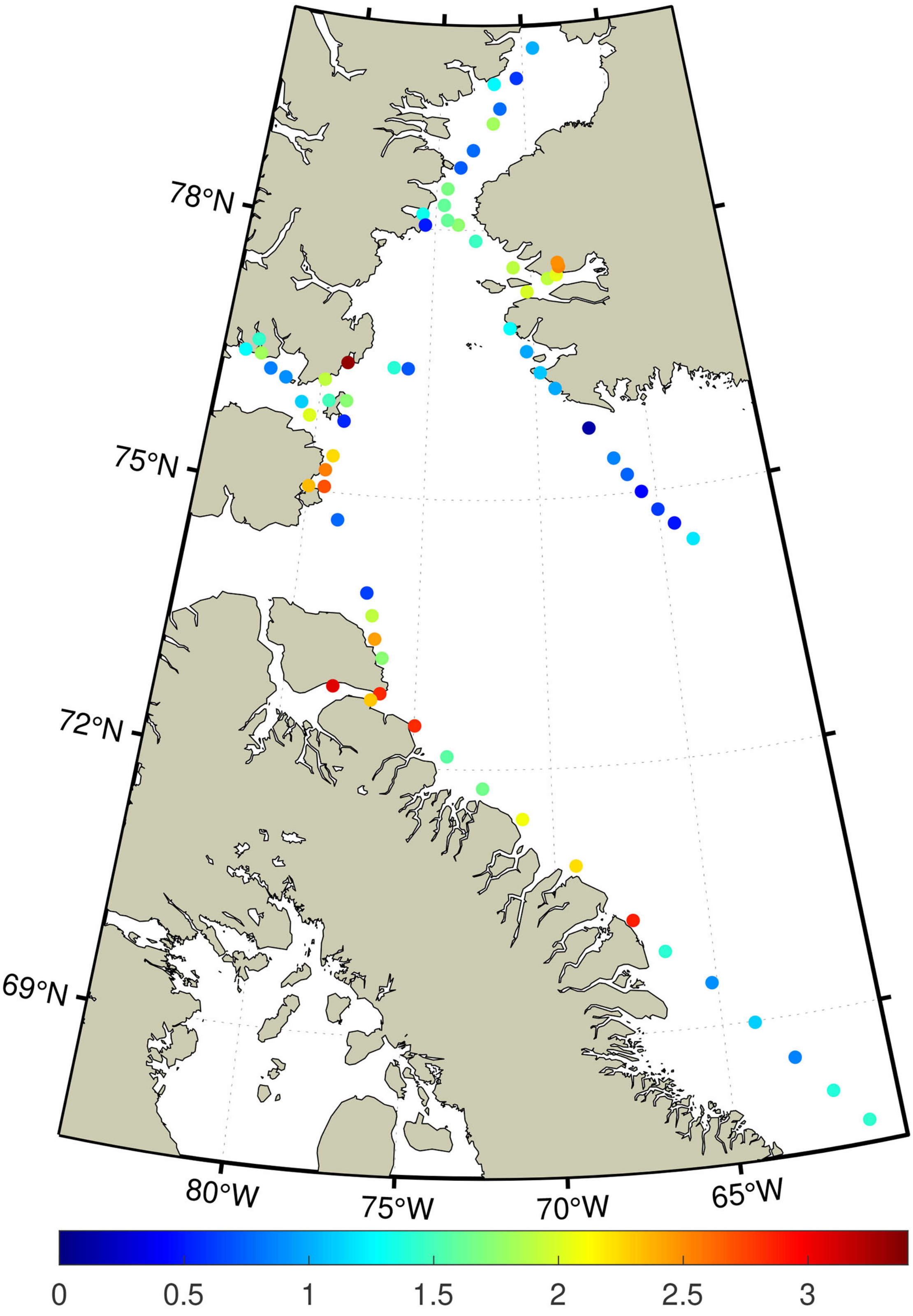

FIGURE 2 | The freshwater content (FWC; units of meters) of the upper 40 m in northern Baffin Bay is indicated by color-coded circles. The FWC ranged from 0.12 to 3.33 m during the 2017 survey.

observations quantify shallow FWC in a data-scarce region of the Arctic.

4. CONCLUSIONS

These preliminary results, therefore, demonstrate the potential for citizen science initiatives to contribute observational data to the ongoing effort to observe and understand the rapidly changing marine Arctic environment. These preliminary results also demonstrate that visiting sailboats can be effective data collection platforms in remote and harsh polar environments. Furthermore, Greenland is the world's largest island and the culture and economy of its citizens are inexorably linked to the sea. In addition to visiting yachts and cruise ships, which only visit Greenlandic waters in the warmer months (Leoni, 2019), citizen science CTD observations should be expanded to acquire data year-round.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://zenodo.org/record/4597385#.YF2cPF1Ki8U.

AUTHOR CONTRIBUTIONS

DC, NP, and SR conceived the study. DC, NP, PL, PP, WT, JC, and GC collected the data. DC performed the quality control and wrote the first draft of the manuscript. SR provided the funding. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.