Underwater Gliders at Memorial University

Summary of Deployments and Collected Data 2006 - 2020

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1. Introduction

This summary report is dedicated to 15 years of glider deployments at Memorial University. A small group of people invested considerable time and energy into developing this technology and furthering its applications. Gliders are relatively small (<2m long) torpedo-shaped and winged autonomous underwater vehicles. They change their buoyancy to sink and use variable pitch angles to generate forward speed from wings similar to winged aircraft. Indeed, these vehicles are called gliders for that reason. They "glide" through the ocean at depths of up to 1000m and can do so repeatedly for months at a time. Owing to their simple design, they are energy efficient but move slowly with forward speeds of 15-35 cm/s depending on the water currents.

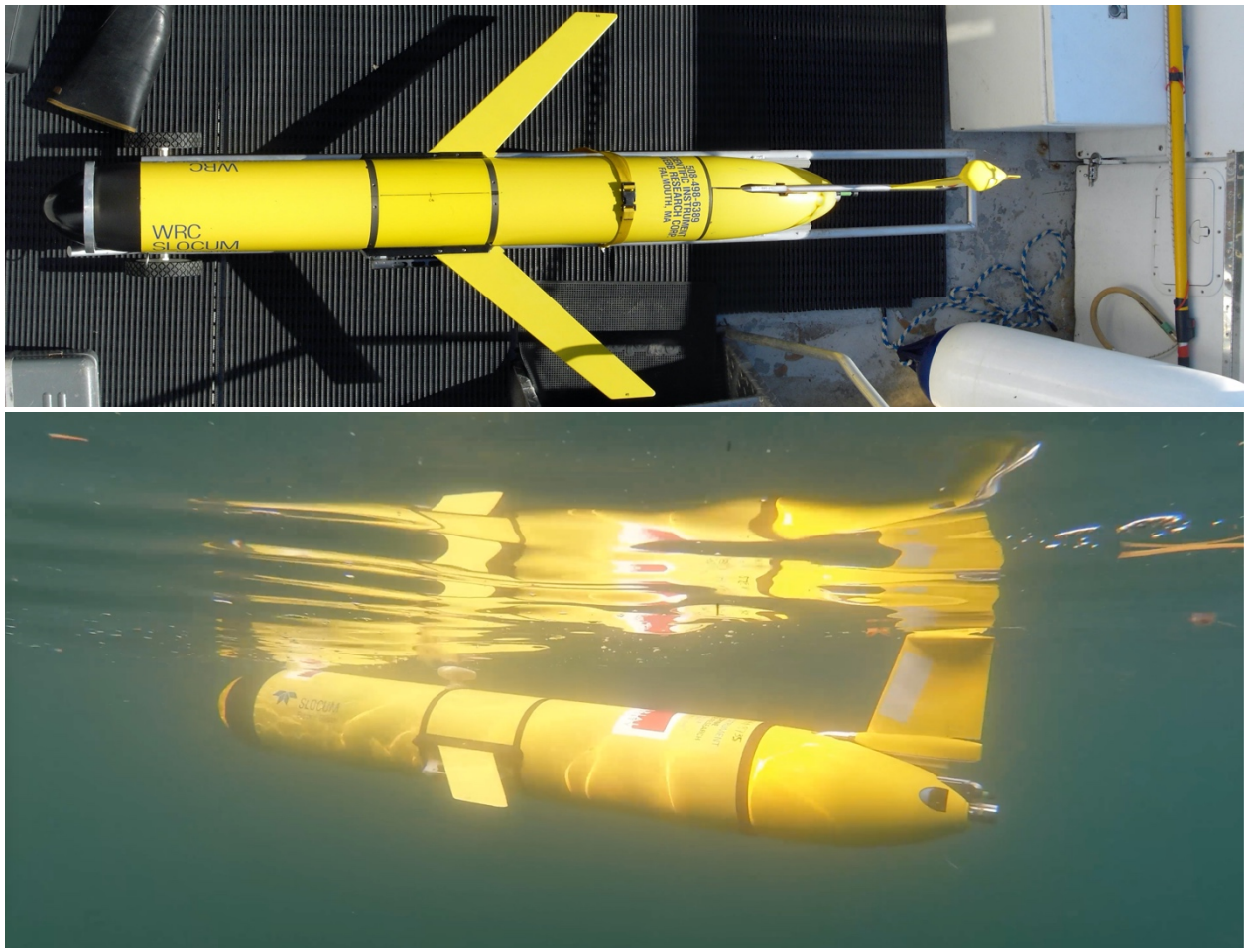

Figure 1.1 Example of early MUN Slocum Glider (Unit 049) with unpumped CTD (SBE41) and a later version G2 1000m Slocum Glider (Unit 473) showing an Oxygen Optode (ADI 4831) and pumped CTD (GPCTD).

Gliders are impressive in their ability to stay at sea for long periods, repeatedly sampling an area with a resolution better than that gained from sparse ship cruises or moorings (Testor et al. 2009, Testor et al. 2019). Gliders can fill in gaps from other sampling strategies and, together with the Argo program, form the backbone of modern global ocean observing system strategies. From the beginning of their development, Memorial has been involved in various projects involving gliders and has contributed to the

development and improvement of the technology. technology. This report details the gliders, missions, and deployments to overview the 15 years of glider deployments at MUN. Some smaller missions (e.g. less than a day) are omitted. Not all glider deployments were found due to archiving issues. However, approximately 90% of the missions are included here. This report is intended as a reference guide for the published glider data sets so that anyone who wants to work with these data can assess the value and utility of the data.

2. Background: Gliders at Memorial University

Memorial has owned and operated gliders since 2004. Drs. Brad deYoung (Physics) and Ralf Bachmayer (National Research Council and later Engineering) began to deploy gliders on and around the Newfoundland shelf to test these vehicles in shorter missions. These early deployments utilizing a small fleet of 4 underwater Slocum gliders (Generation 1) leading to many advancements in glider operation, data collections, glider sensors, navigation and missions. These early gliders used alkaline batteries enabling continuous glider deployments of up to a month or up to 1000 km's with dive depths of up to 200m. These early deployments included deployments around Greenland ice shelves to advance under ice glider missions. Work by Charlie Bishop and Dr. deYoung led to new algorithms to correct science data from gliders paving the way towards studying ocean shelf dynamics with gliders to capture heat, salt and oxygen exchange. Indeed the 2006 CBS glider missions with an oxygen optode were among the first worldwide.

A more formal glider group emerged at MUN in 2012 with the creation of the Autonomous Ocean Systems Laboratory (AOSL) led by Drs. Bachmayer and de Young that continued using glider technology and other platforms to explore various applications of autonomous ocean systems. Projects of AOSL over the years focussed on iceberg profiling, underwater terrain-aided navigation, development of a glider with a magnetically geared thruster and underwater navigation with sonar and acoustic modems. Several larger pan-Canadian science projects came into existence after 2012, explicitly integrating glider observations into the core science themes, including the NSERC-CCAR-funded VITALS project studying heat, oxygen and salt transports across the Labrador Sea. This significant project involved several postdocs, PI's and many HQP that resulted in 10 glider deployments on the Labrador Shelf, Newfoundland and the central Labrador Sea. More gliders were added to the fleet during that period. The next generation gliders (G2) have made it possible to dive deeper, carry more instruments and stay deployed for more prolonged periods using new lithium batteries and extended energy bays. New science sensors were also integrated, such as the prototype Aanderaa pCO_2 optode. One deployment carried a glider across the Labrador shelf into the central Labrador Sea to sample oxygen and CO_2 for four months in synchronization with other ocean observations from moorings and floats.

The next chapter of glider operations at Memorial is underway with the Ocean Frontier Institute (OFI)interdisciplinary projects combining academia, government, and industry to understand the ocean's value chain, including understanding the Atlantic region's science gaps. Core projects include the Northwest Atlantic Carbon sink to understand the storage of CO_2 in the Labrador Sea and implications for the regional and global climate, economies and ability for people to enjoy the ocean's tangible benefits. Other projects focus on using ocean observations in other areas outside traditional research projects to broaden scientific research's benefits. Together with the CFI-funded Development of Autonomous Marine Observing Systems (DAMOS) Infrastructure project, Memorial will be in a position to continue participating in key marine research themes, addressing questions about the ocean. DAMOS brought

additional gliders to MUN and other platforms to enhance the capabilities to conduct autonomous ocean observations.

Table 1. Slocum Glider Inventory, Projects and Status

Glider	Type	Sensors	Fate / Status	Projects	Years Active
Unit 046 (Nunkaysa)	G1 Shallow	CTD SBE41, O_2 Optode 3835	Lost during deployment	NRC, Ocean Glider Canada DFO Pacific	2004- 2013
Unit 047 (Narwhal)	G1 Shallow	CTD SBE41, Acoustic Modem, Turner Fluorometer	MUN	NRC, Iceberg profiling, Terrain aided navigation	2004 - Present
Unit 048 (Scidaana)	G1 Shallow	CTD SBE41, O_2 Optode 3835	Transferred to DFO Pacific	NRC, Sensor performance, DFO contract Fortune Bay Mission, DFO Pacific, Ocean Gliders Canada	2004-
Unit 049	G1 Shallow	CTD SBE41, DVL, ADCP, MUN Thruster	Lost during deployment	NRC, Sensor performance, Glider terrain aided navigation, thruster development, iceberg surveys	2004- 2012
Unit 334	G2 200m	CTD GPCTD, Acoustic Modem, Custom BB Proglet, MUN Thruster	On extended project at GSO URI	AOSL, VITALS, Iceberg profiling and underwater navigation using acoustic modems	2012 - Present
Unit 354 (Pearldiver)	G2 1000m	CTD GPCTD, ADI O_2 4831, ADI CO2 4797, orig. Wetlabs ECOPUC Triplet	MUN	VITALS, HOTsEALS, OFI	2012 - Present
Unit 472	G2 1000m Hybrid	CTD GPCTD, ADI O_2 4831, ADI CO_2 4797 Optode, Wetlabs ECOPUC Triplet, TWR Thruster	Lost during deployment	VITALS	2013 - 2015
Unit 473 (Gannet)	G2 1000m	CTD GPCTD, ADI O_2 4831, ADI CO_2 4797 Optode, MUN Thruster	MUN, Damaged during deployment on repair at TWR	VITALS, OFI, HOTSeALS	2013 - 2019
Unit 805 (Sunfish)	G3 1000m Hybrid	CTD RBR, O_2 Optode, Wetlabs ECOPUC Triplet	MUN, under warranty repair	OFI, DAMOS	2019 - Present
Unit 806 (Migaloo)	G3 1000m Hybrid	CTD RBR, O_2 Optode, SBE pH Integration	MUN, under warranty repair	OFI, DAMOS	2019 - Present

3. Glider Deployments Summary

To date, MUN gliders have travelled a total of 14’663 mission km, 620 deployment days and collected 25’108 total glider profiles. Memorial’s earliest recorded glider deployment is from 2006 for which data is found and the longest deployment was a 7-month mission into the Central Labrador Sea as part of the HOTSeALS project in 2019-2020. Table 3.1 summarizes all the glider deployments recorded, however not all of them are included and processed such as the Twillingate missions to study icebergs.

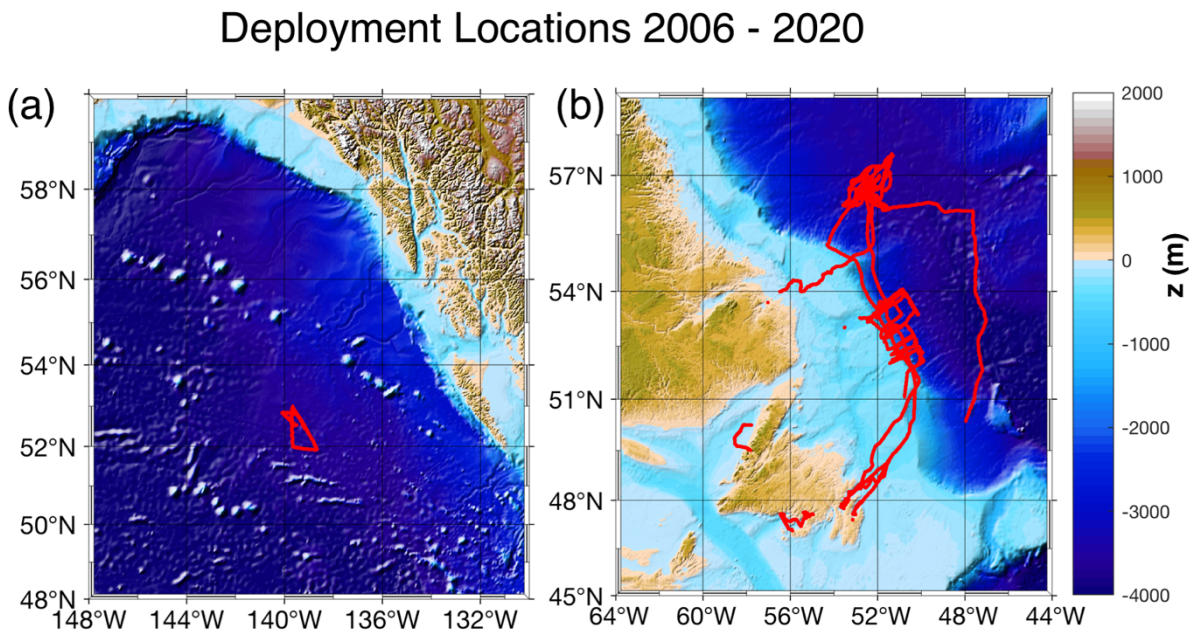

Figure 3.1 Map of Glider Deployment Sites 2006 - 2020 (a) Pacific Region and (b) North-West Atlantic Region.

Table 3.1 List of MUN Glider Deployments (All deployments involved either Ralf Bachmayer or Brad deYoung or both)

Year	Where	Objective	Glider	Funding	Key People
2006	CBS	Sensor tests	Unit 048	NRC / NSERC	Charlie Bishop,
2006	Trinity Bay/ CBS		Unit 049		
2012	Pacific near OWS Papa	Hydrographic Data Collection	Unit 046 (Nunkaysa)	DFO / ONC	Paul LaCroix
2012			Unit 048 (Scidaana)		
2013	Fortune Bay	External Contract	Unit 048	DFO	Andry Ratsimandresy
2013	Trinity Bay	Sensor tests	Pearldiver	VITALS	Brian Claus

2013	Bonne Bay	Fluxgate tests	Unit 334	AOSL IOSS	Brian Claus
2014	Labrador Shelf	Fluxgate	Unit 334	VITALS	Brian Claus Tara Howatt Jaime Palter Robin Matthews
2014		Ekman Transport and Eddy Exchange	Pearldiver		
2014			Unit 473		
2014	Trinity Bay	Virtual mooring	Unit 472	VITALS	
2014			Unit 473		
2015	Trinity Bay	CO2 Tests	Unit 472	VITALS	Robin Matthews Mark Downey
2015	Labrador Sea	CO2 Observ.	Unit 472		
2015	CBS	Terrain Navigation	Unit 049	AOSL IOSS	Brian Claus
2015	Twillingate	Iceberg Studies	Unit 334	AOSL IOSS	Mingxi Zhou
2016	Trinity Bay	CO2 Tests	Unit 473	VITALS	Robin Matthews Mark Downey
2016	Labrador Sea	CO2 Depl.			
2016	Twillingate	Iceberg Scanning	Unit 334	AOSL IOSS	Mingxi Zhou
2017					
2018	Trinity Bay	CO2 Tests	Unit 473	OFI, VITALS	N. Bronikowski Mark Downey Mingxi Zhou
2019	Bonne Bay	Mooring	Unit 473	OFI	
2019	Gulf of St. Lawr.	Hydrography	Pearldiver	OFI	
2020	Labrador Sea	T,S Exchange	Pearldiver	OFI	

4. List of Glider Deployments

4.1 unit_048 Conception Bay Mission 2006

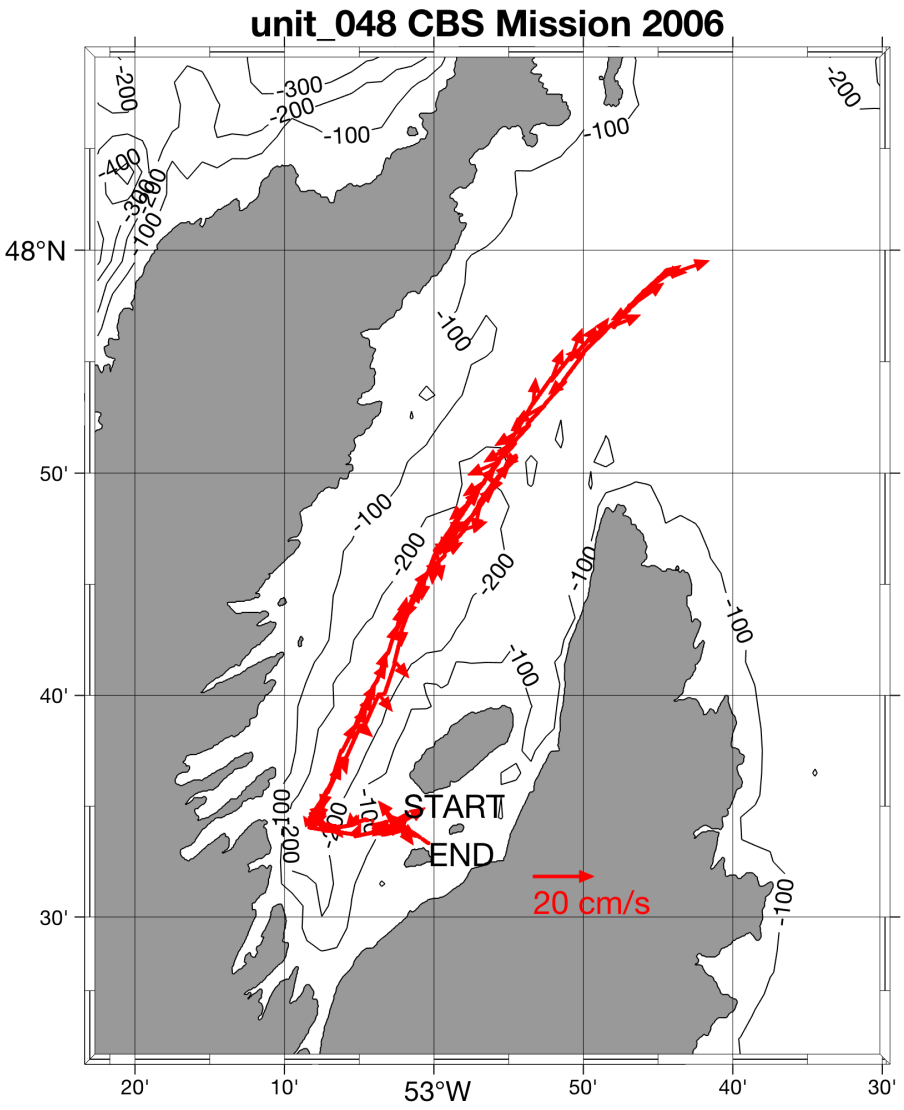

Figure 4.1.1. Mission map of Conception Bay Mission in 2006 for Glider Unit_048 to test new Aanderaa Oxygen Optode 3835 and collect CTD data.

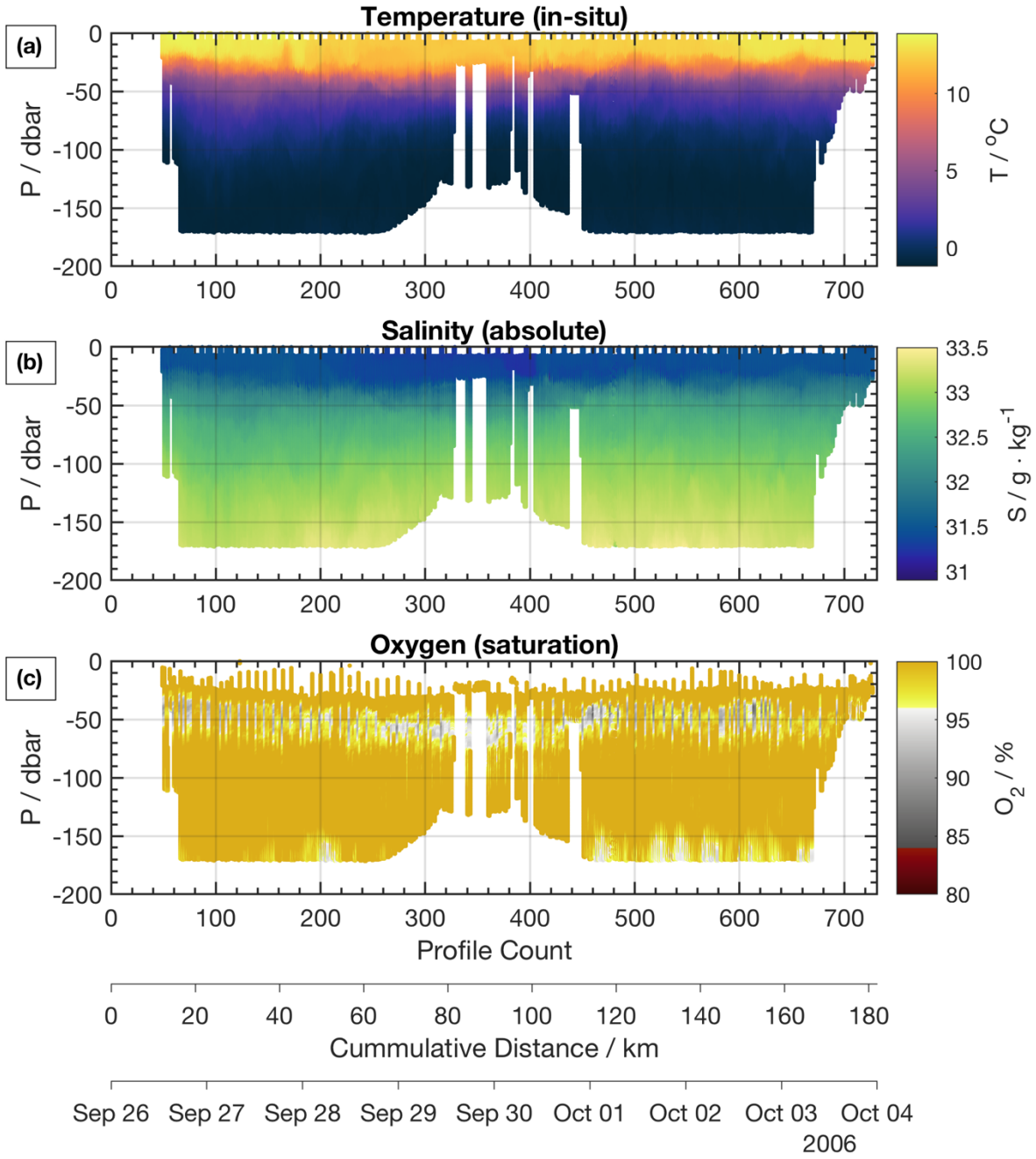

Figure 4.1.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.2 unit_049 Newfoundland Shelf Mission 2006

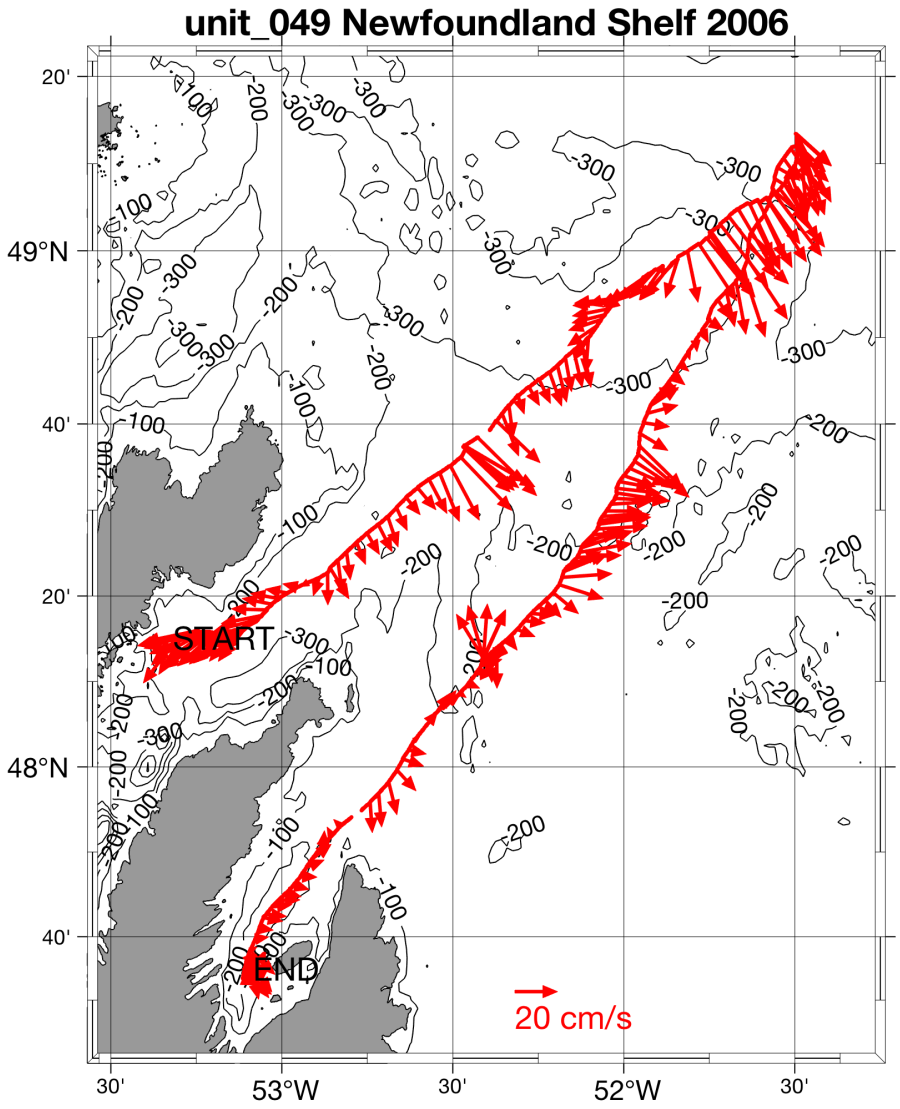

Figure 4.2.1 Mission map of Newfoundland Shelf Mission from Trinity Bay to Conception Bay in 2006 for Glider Unit_049 to collect CTD data for new sensor performance study.

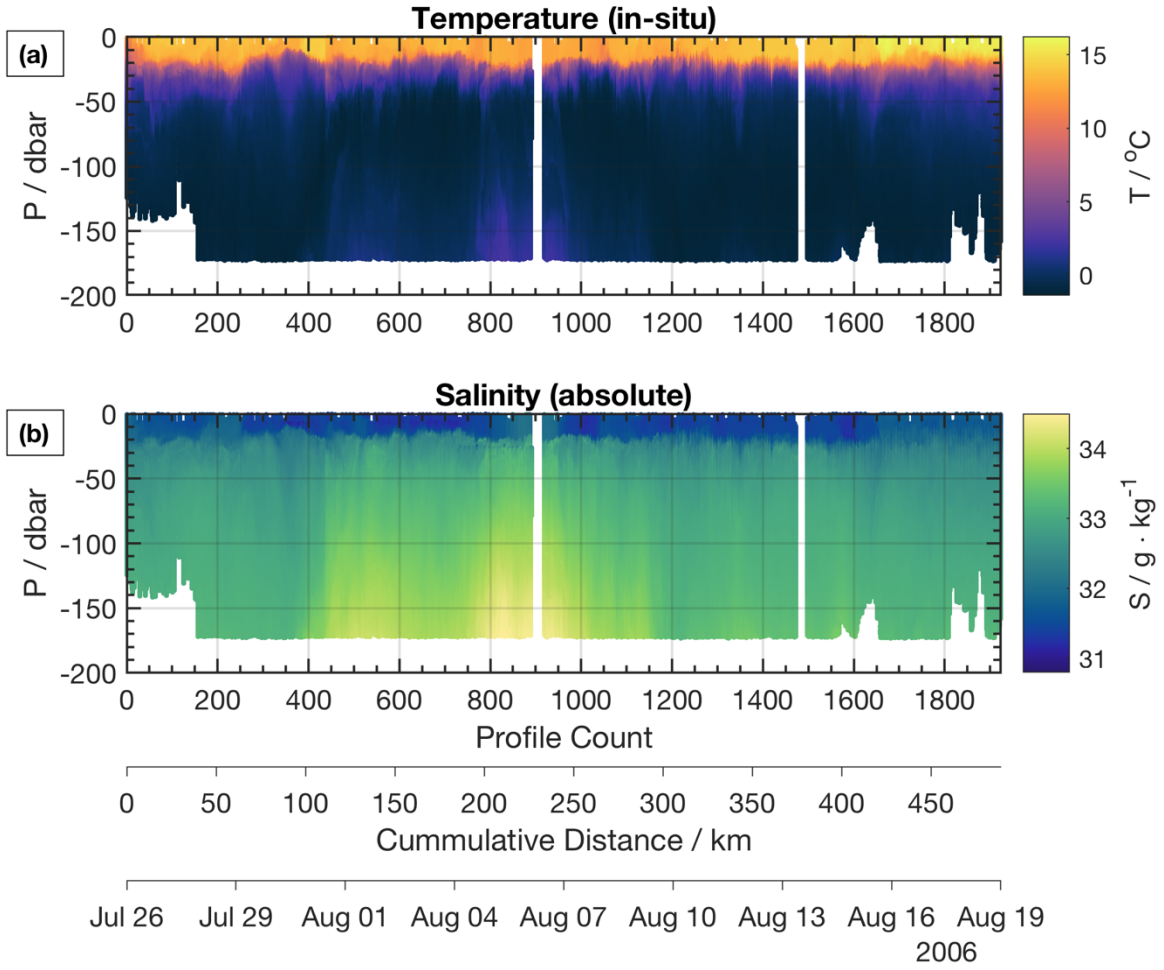

Figure 4.2.2 Collected hydrographic data (a) in-situ temperature, (b) absolute salinity calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.3 Fortune Bay Deployment

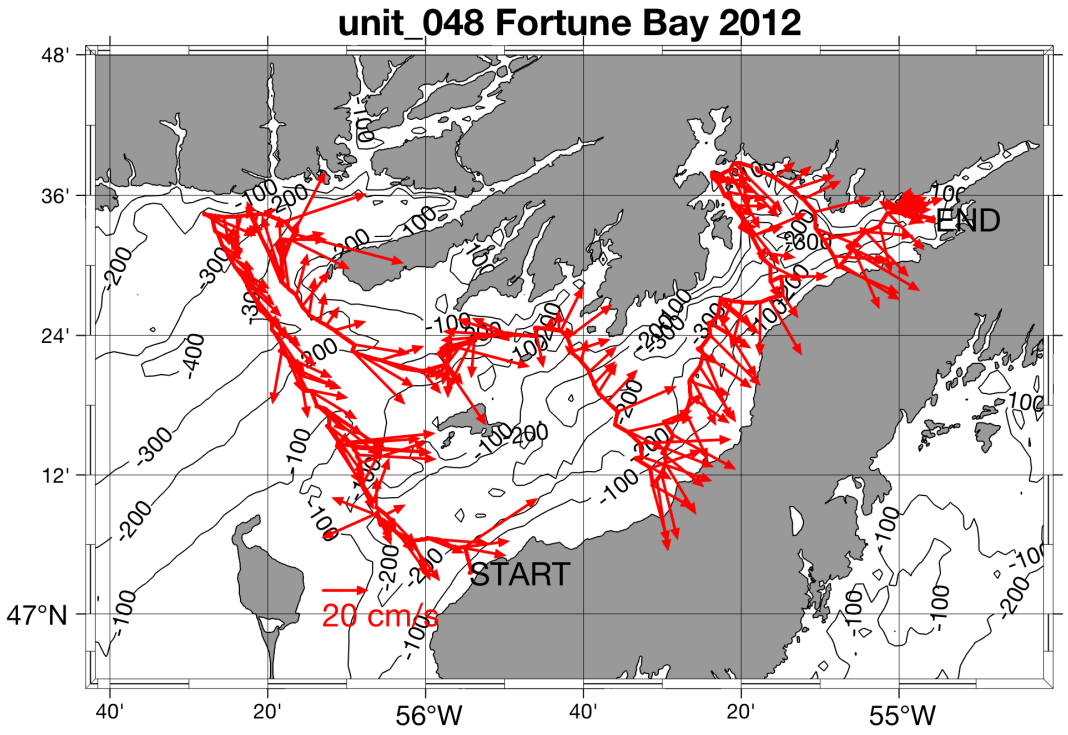

Figure 4.3.1. Mission map of DFO/Memorial Unit 048 deployment in Fortune Bay, March 2012.

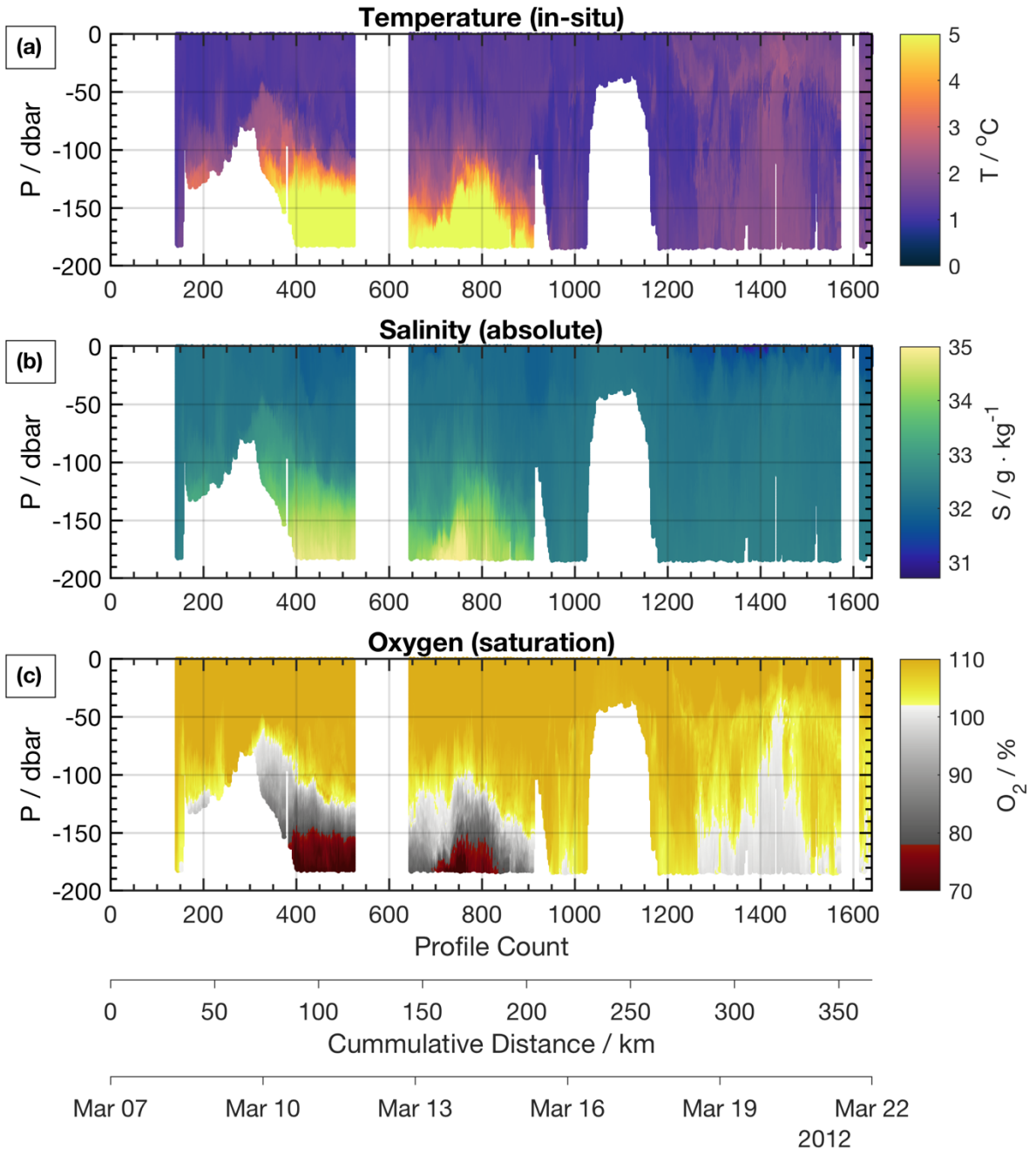

Figure 4.3.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.4 Nunkaysa Pacific Deployment 2012

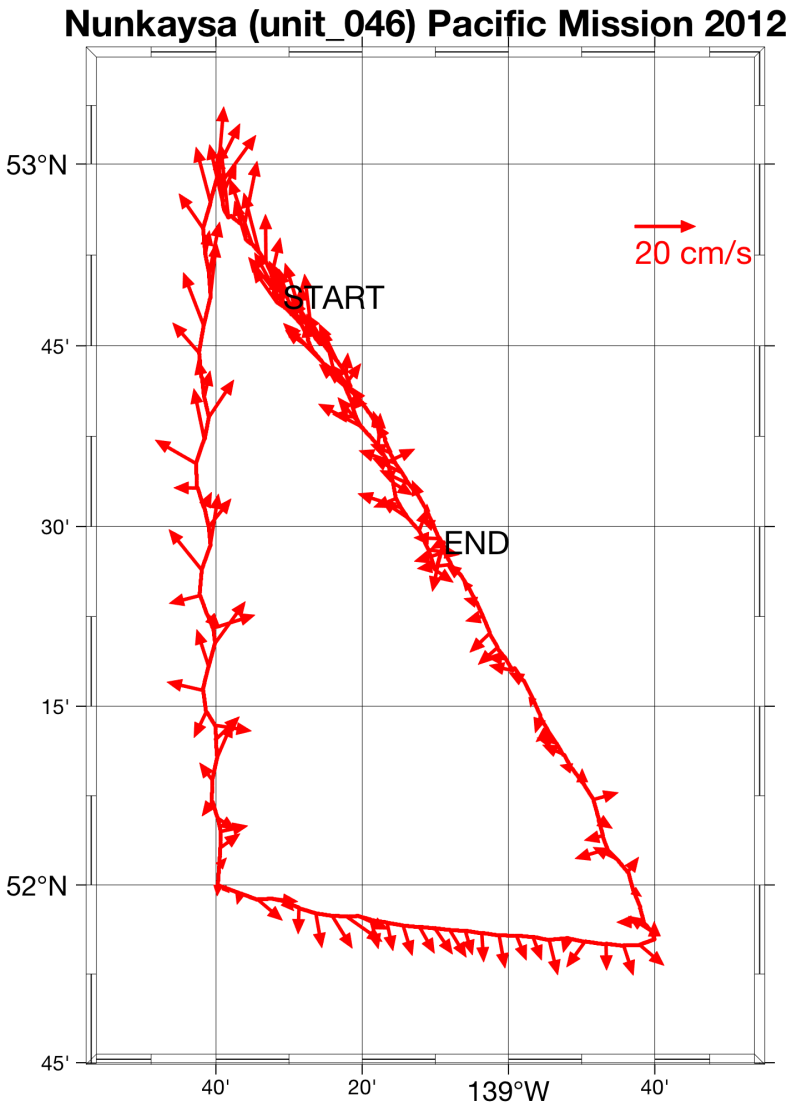

Figure 4.4.1. Mission map of DFO Pacific Region / Ocean Gliders Canada deployment of Nunkaysa (ex. Unit_046) in the Pacific Ocean.

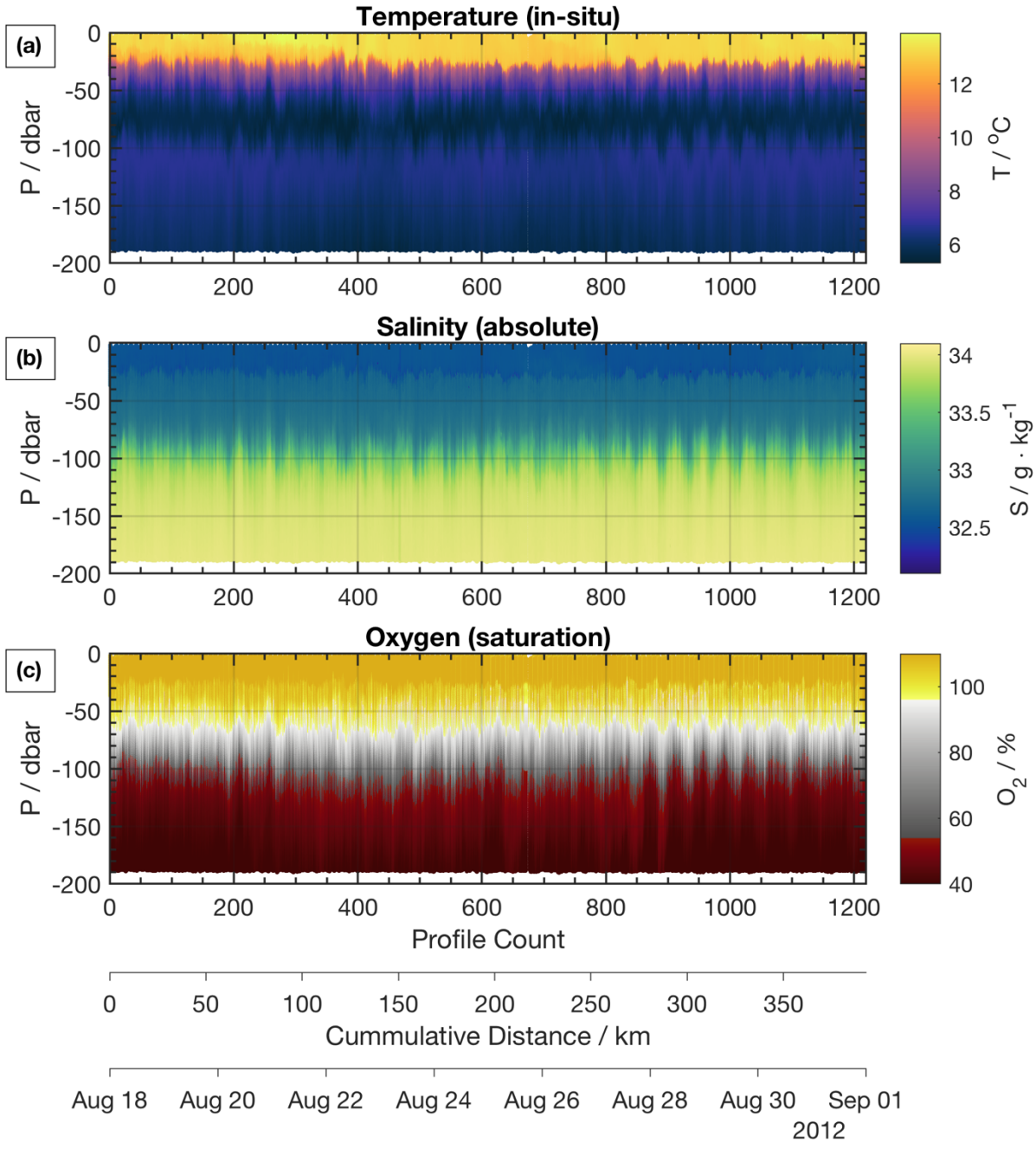

Figure 4.4.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.5 Scidaana Pacific Deployment 2012

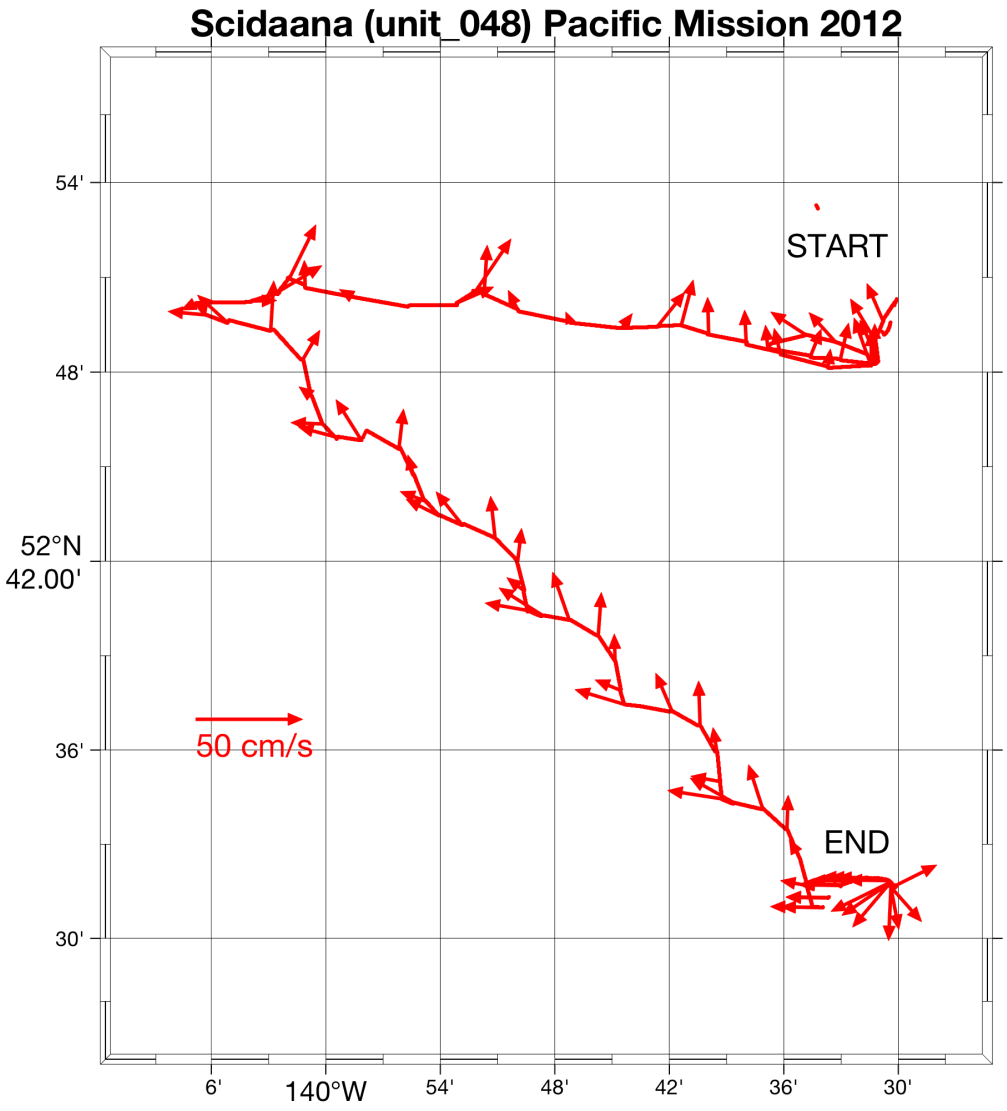

Figure 4.5.1. Mission map of DFO Pacific Region / Ocean Gliders Canada deployment of Scidaana (ex. Unit_048) in the Pacific Ocean

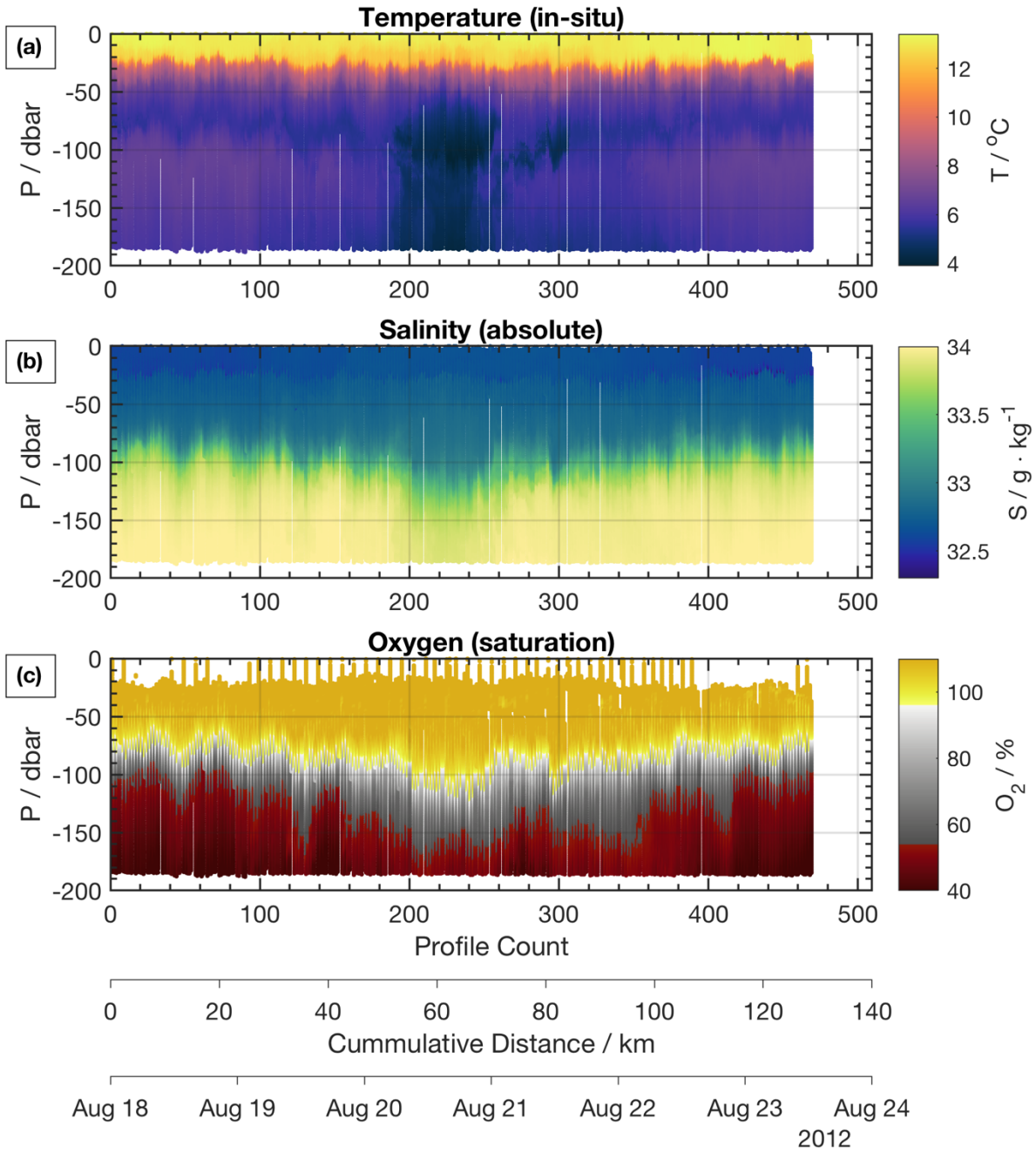

Figure 4.5.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.6 unit_049 Holyrood Mission 2013

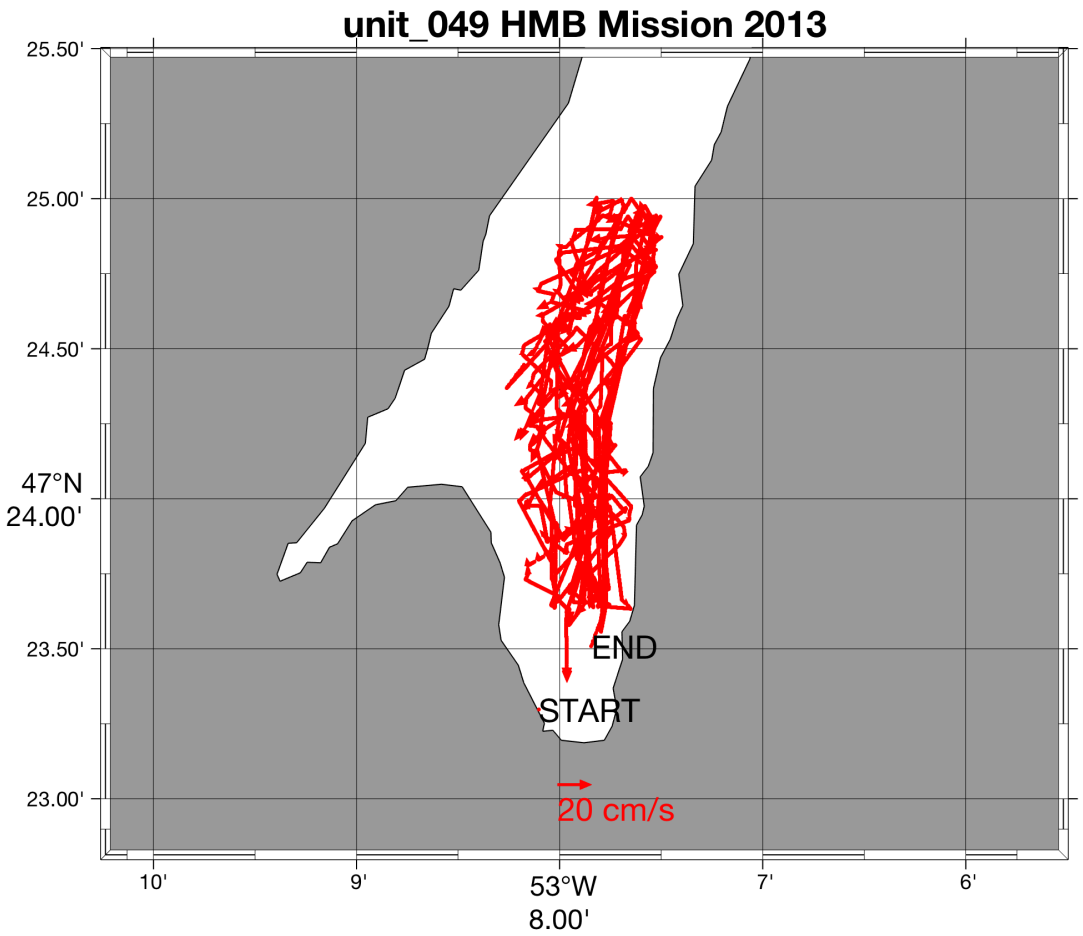

Figure 4.6.1. Holyrood Marine Base (HMB) extended deployment of Unit_049 in 2013 as part of Terrain Aided Navigation (TAN) project.

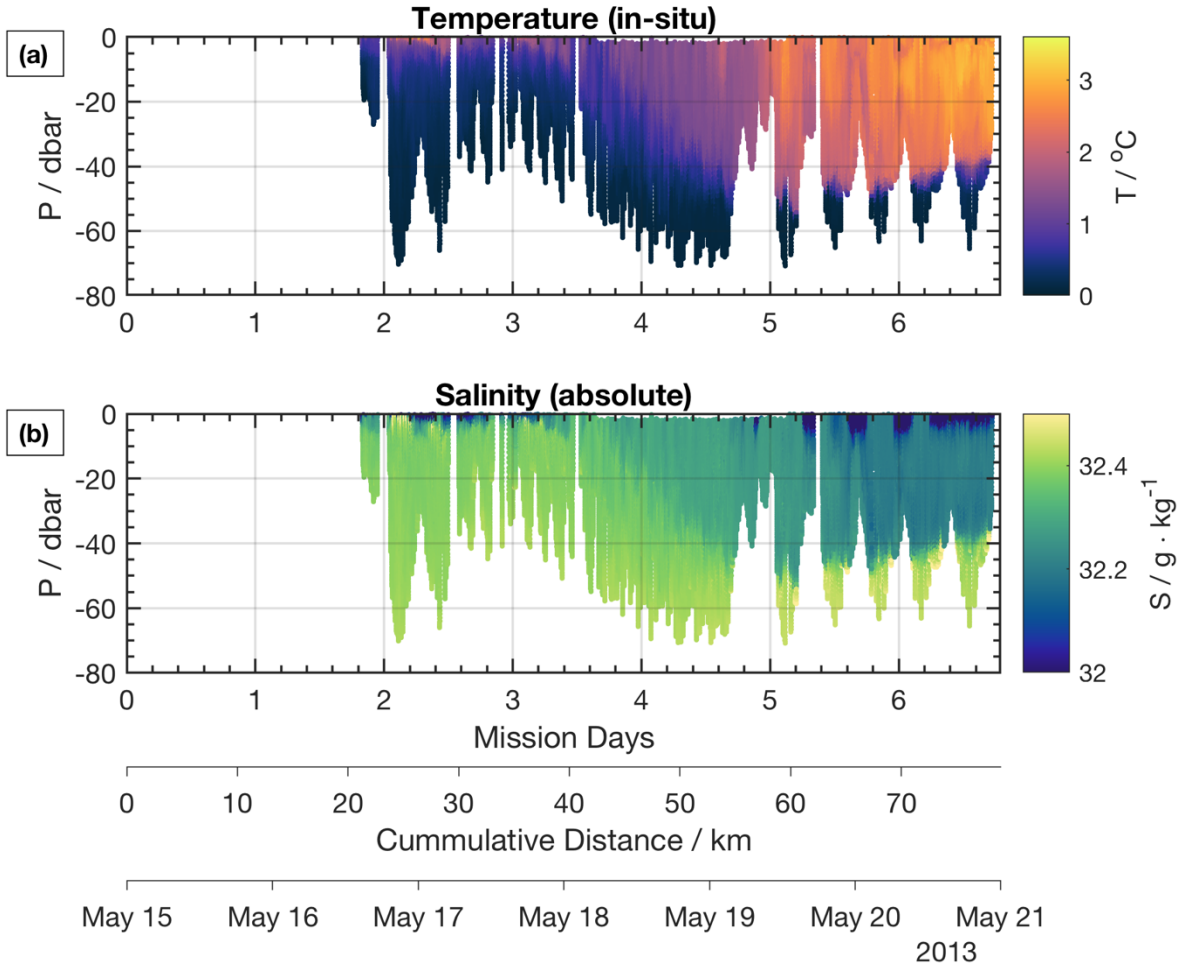

Figure 4.6.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.7 Pearldiver Trinity Bay Tests 2013

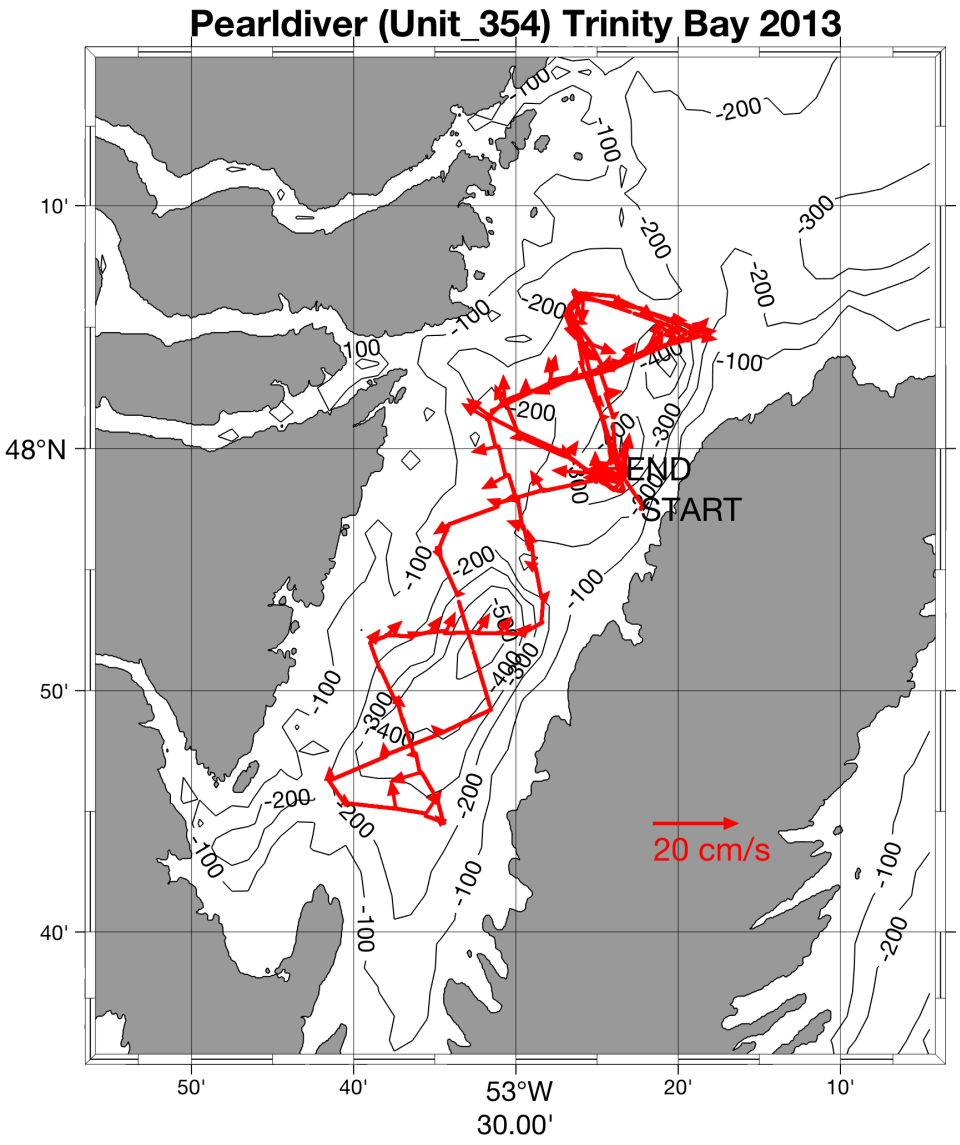

Figure 4.7.1. Deployment map of Pearldiver Trinity Bay Mission in 2013 to test sensors and glider

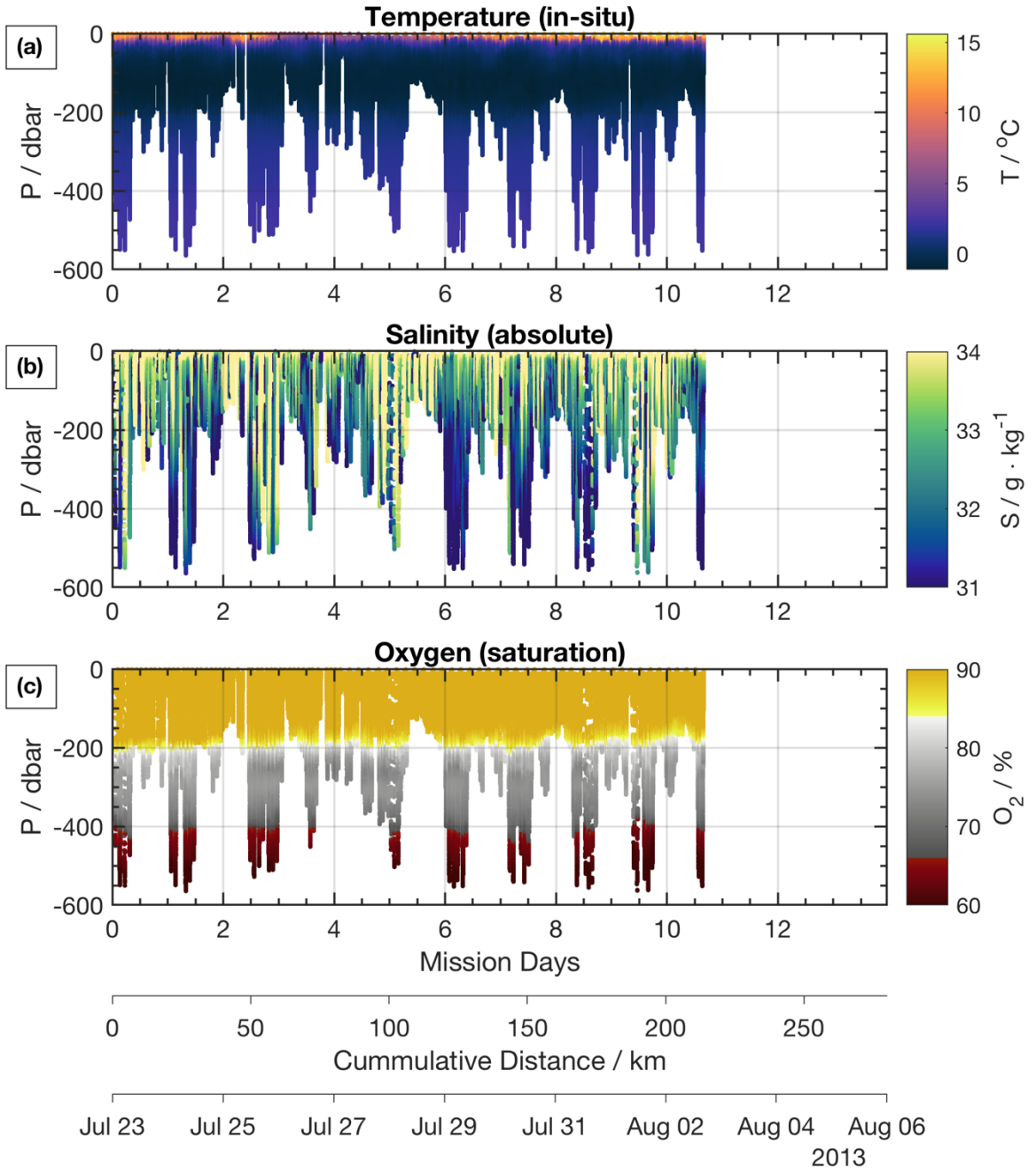

Figure 4.7.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed mission days. The time axis shows the length of deployment and is for scale. Data is very spikey for the CTD due to malfunctioning pump.

4.8 unit_334 Bonne Bay Mission 2013

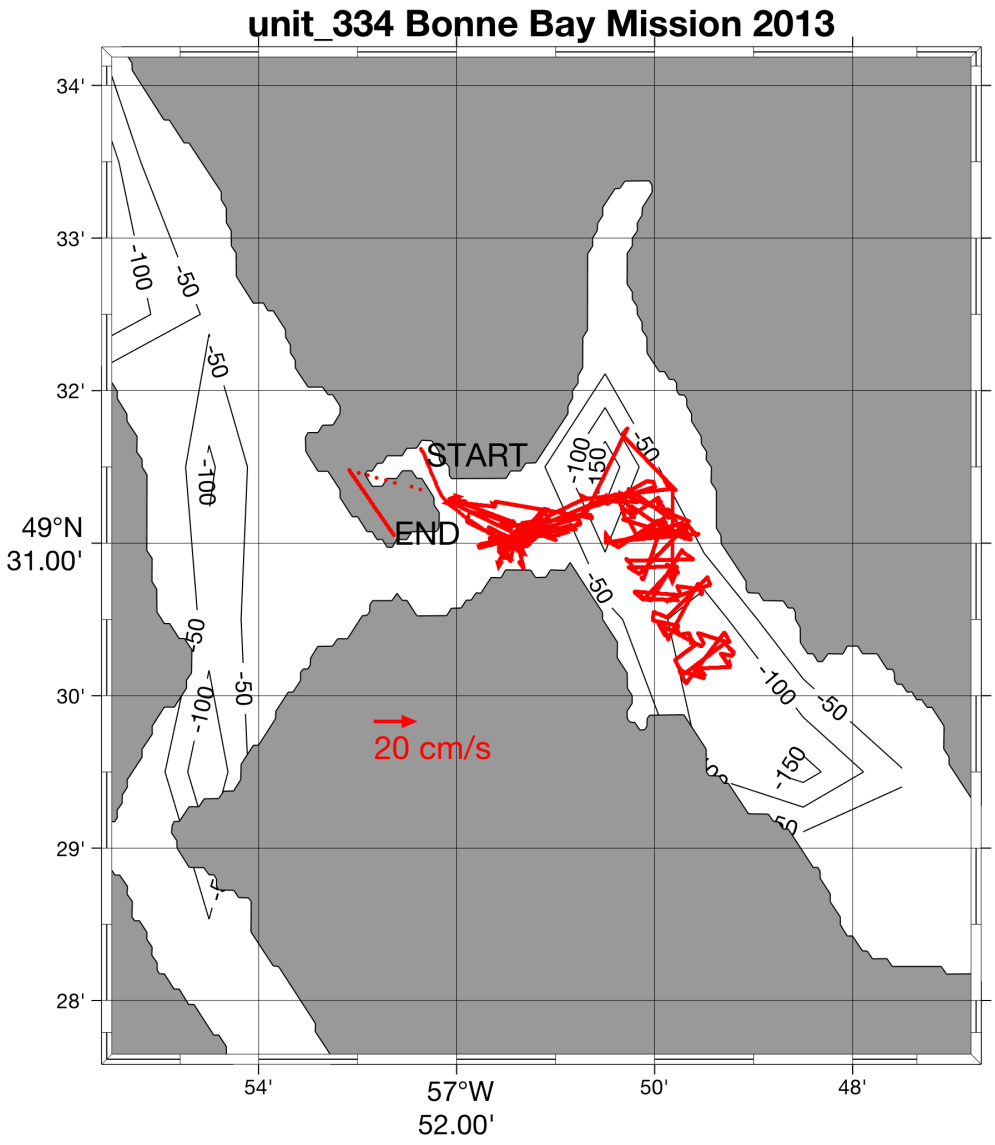

Figure 4.8.1. Mission map of Bonne Bay deployment for Glider Unit_334 in December, 2013.

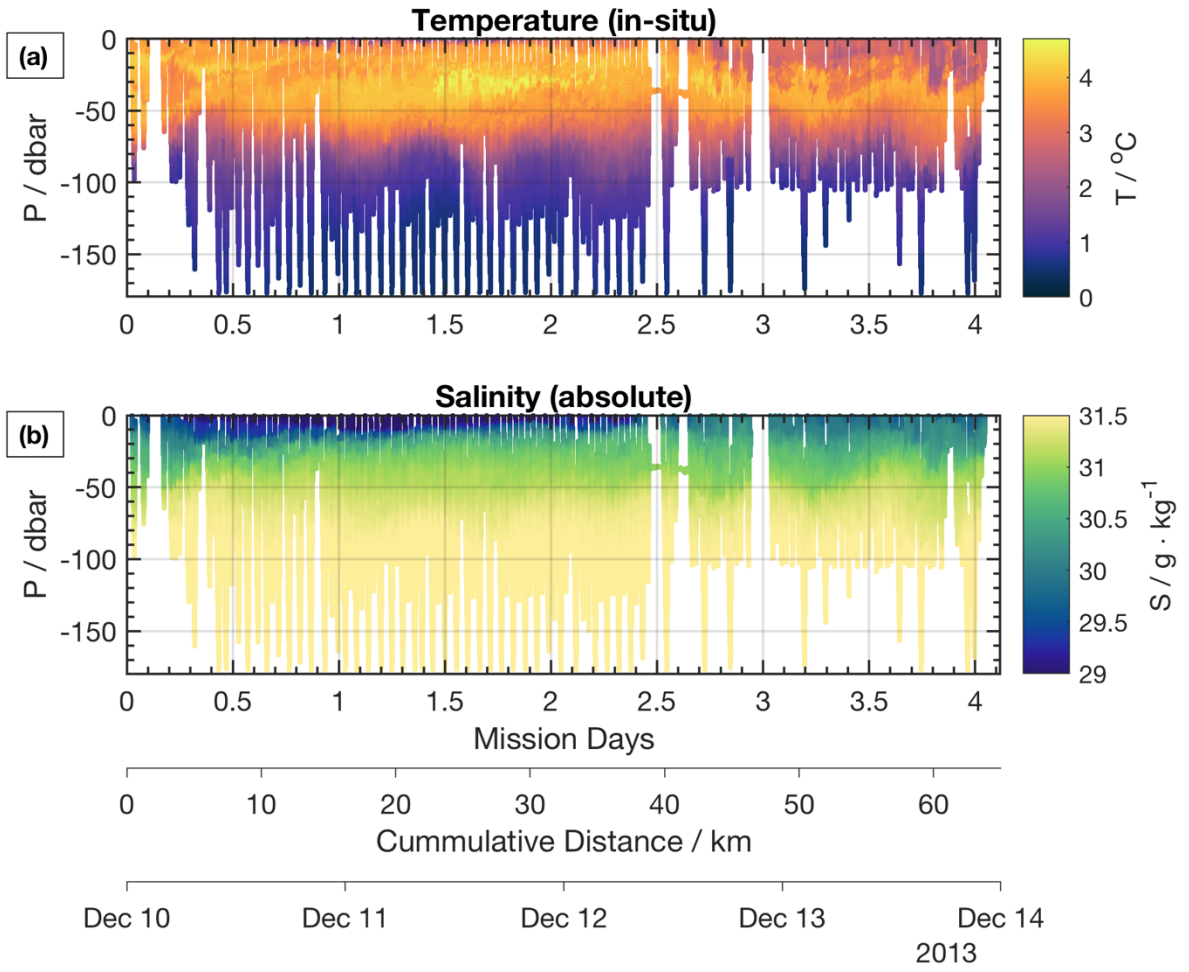

Figure 4.8.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity calculated from the GSW toolbox. Axes are plotted over pressure and mission days. The time axis shows the length of deployment and is for scale.

4.9 unit_334 Labrador Shelf Mission 2014

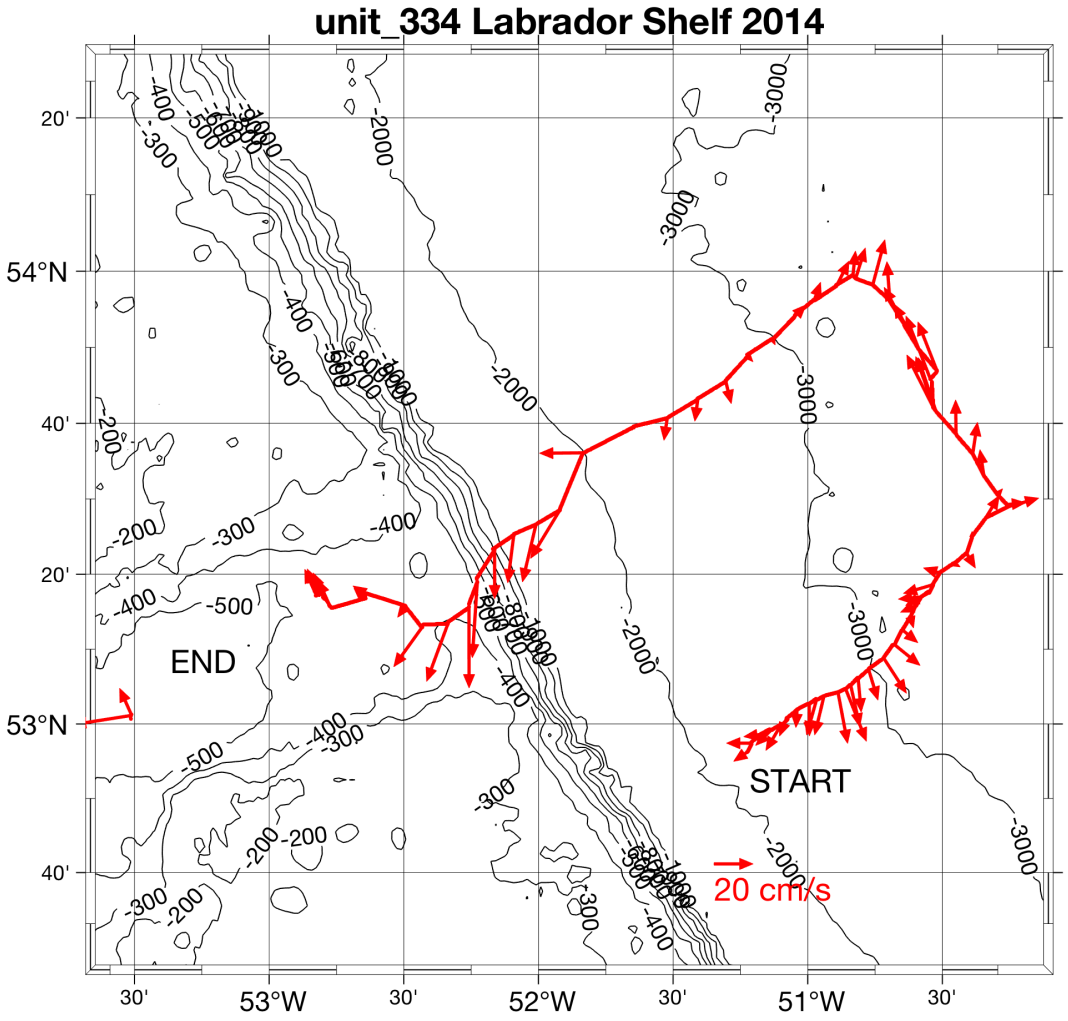

Figure 4.9.1. Deployment map of Labrador Shelf Mission in 2014 for Glider Unit_334, part of Ventilations, Interactions and Transports Across the Labrador Sea (VITALS) Program to capture heat and salt exchange across the Labrador Shelf. The glider suffered from a hair leak and had to be recovered early.

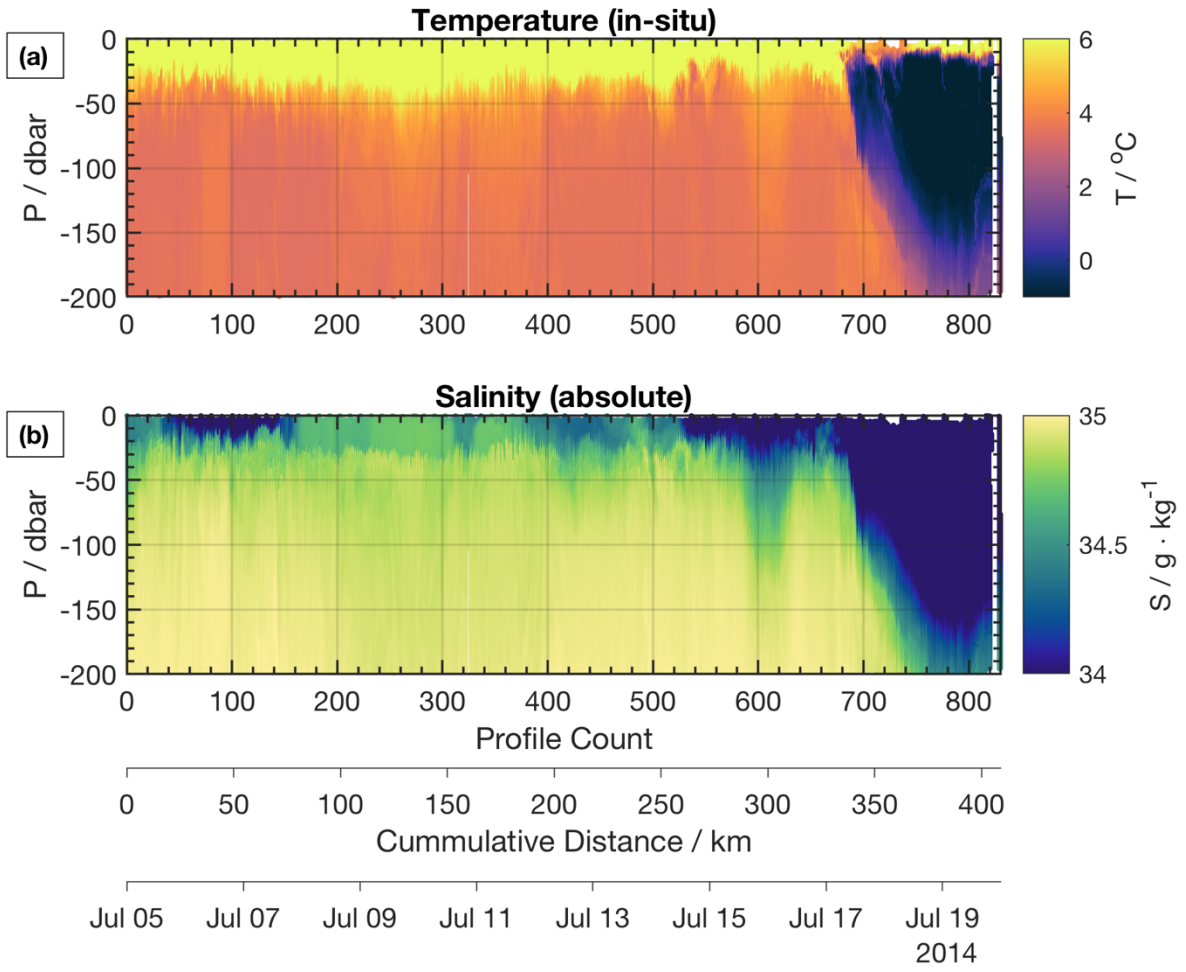

Figure 4.9.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.10 Pearldiver Labrador Shelf Mission 2014

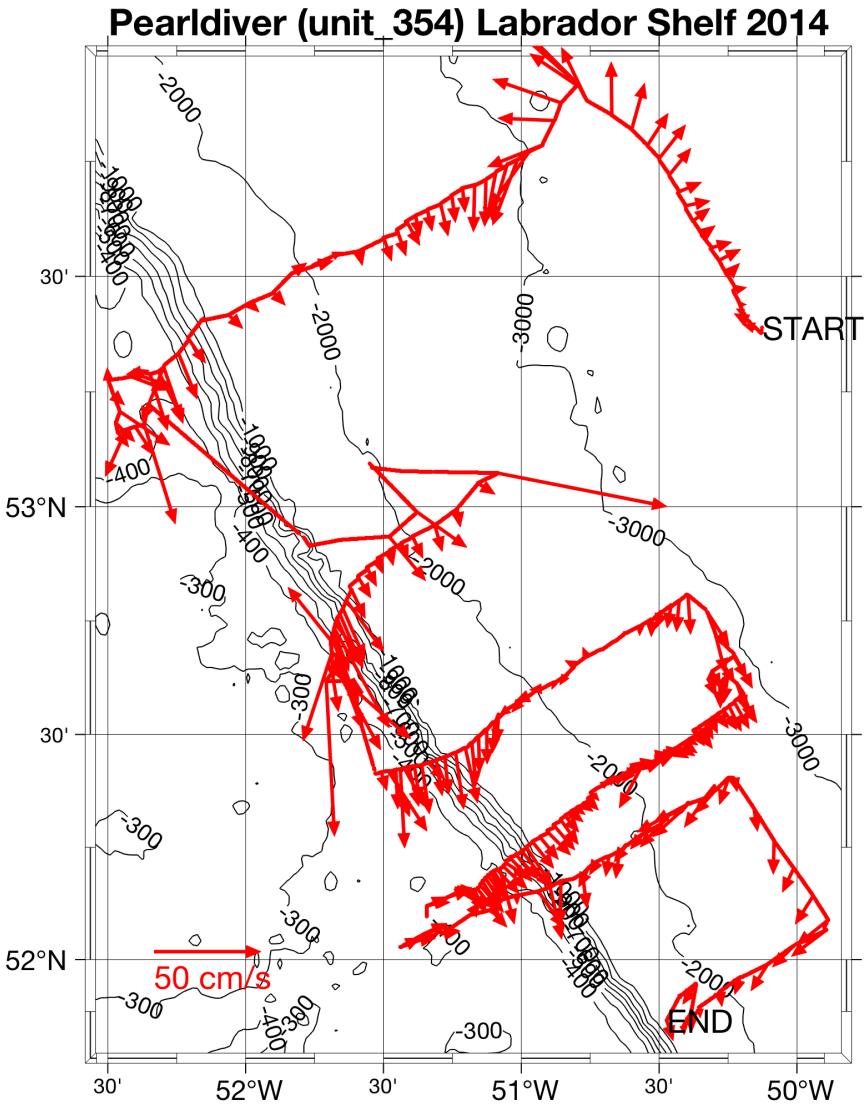

Figure 4.10.1. Deployment map of Labrador Shelf Mission in 2014 for Glider Pearldiver (ex. Unit_354), part of Ventilations, Interactions and Transports Across the Labrador Sea (VITALS) Program to capture heat and salt exchange across the Labrador Shelf.

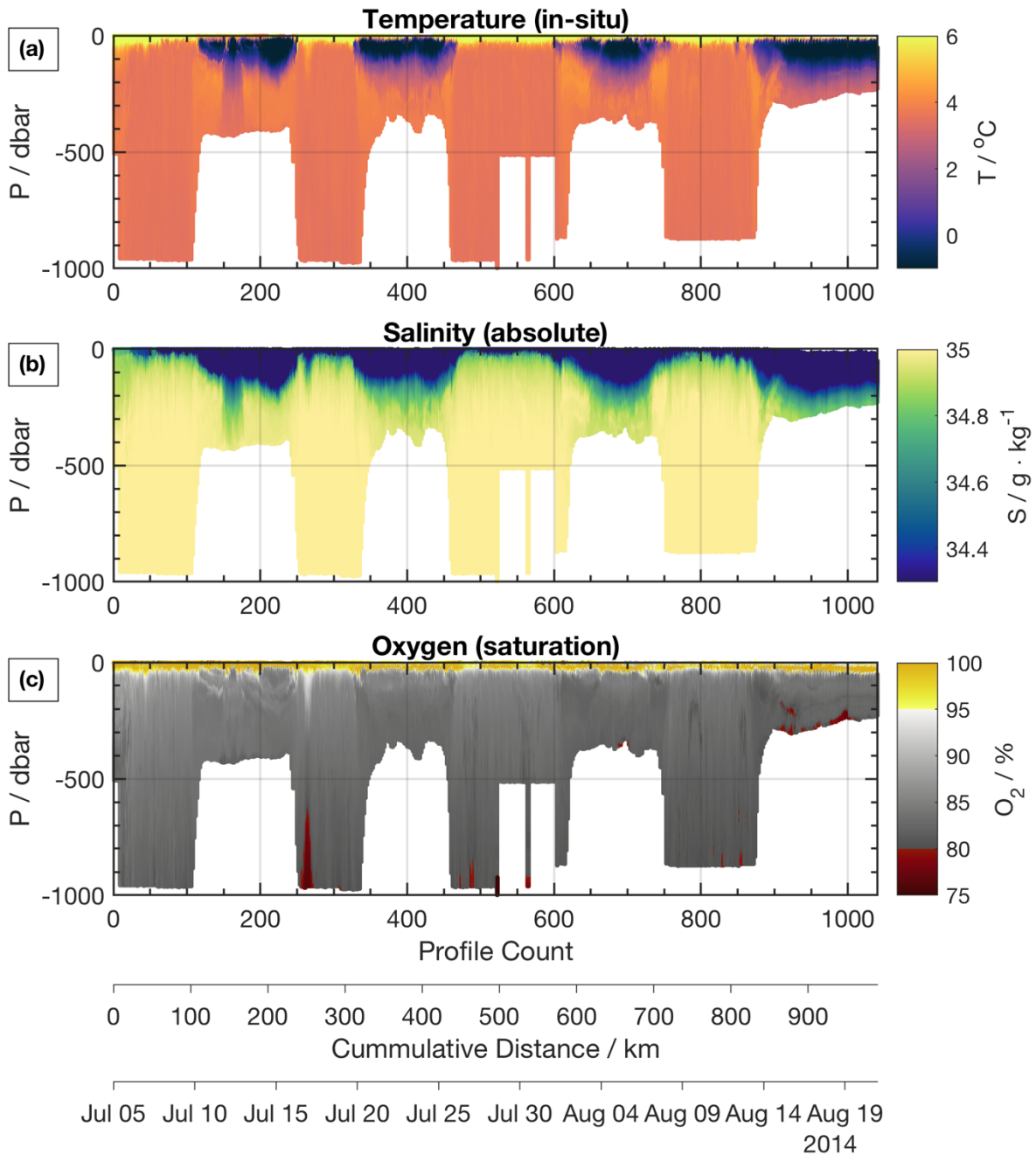

Figure 4.10.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.11 unit_473 Labrador Shelf Mission 2014

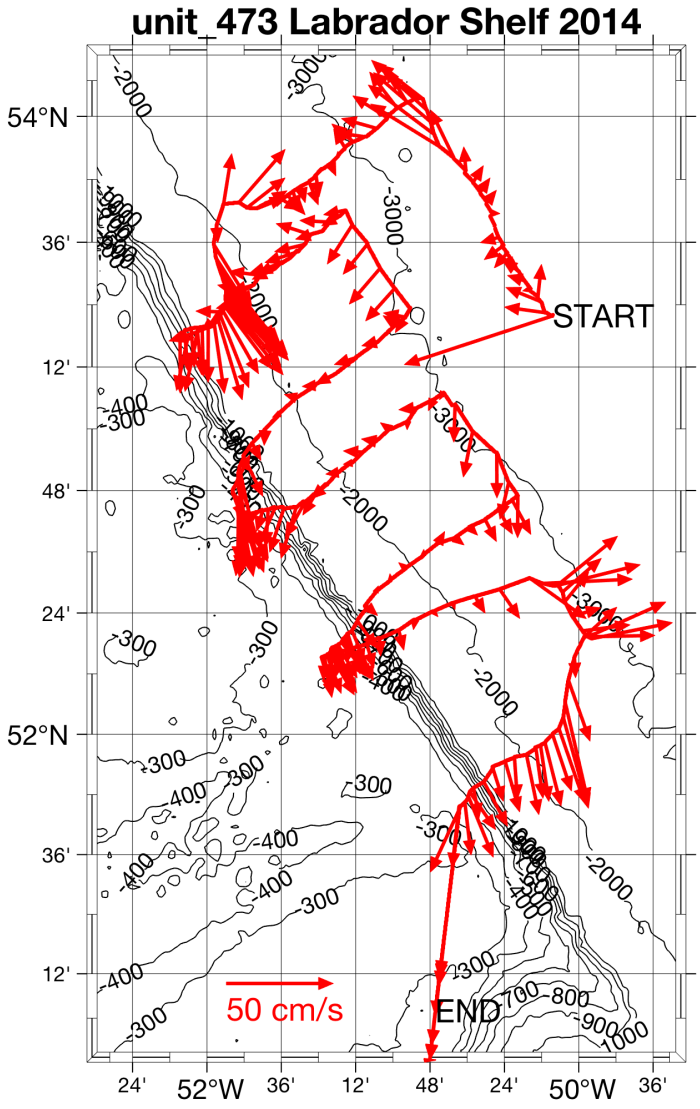

Figure 4.11.1. Deployment map of Labrador Shelf Mission in 2014 for Glider Pearldiver (ex. Unit_354), part of Ventilations, Interactions and Transports Across the Labrador Sea (VITALS) Program to capture heat and salt exchange across the Labrador Shelf.

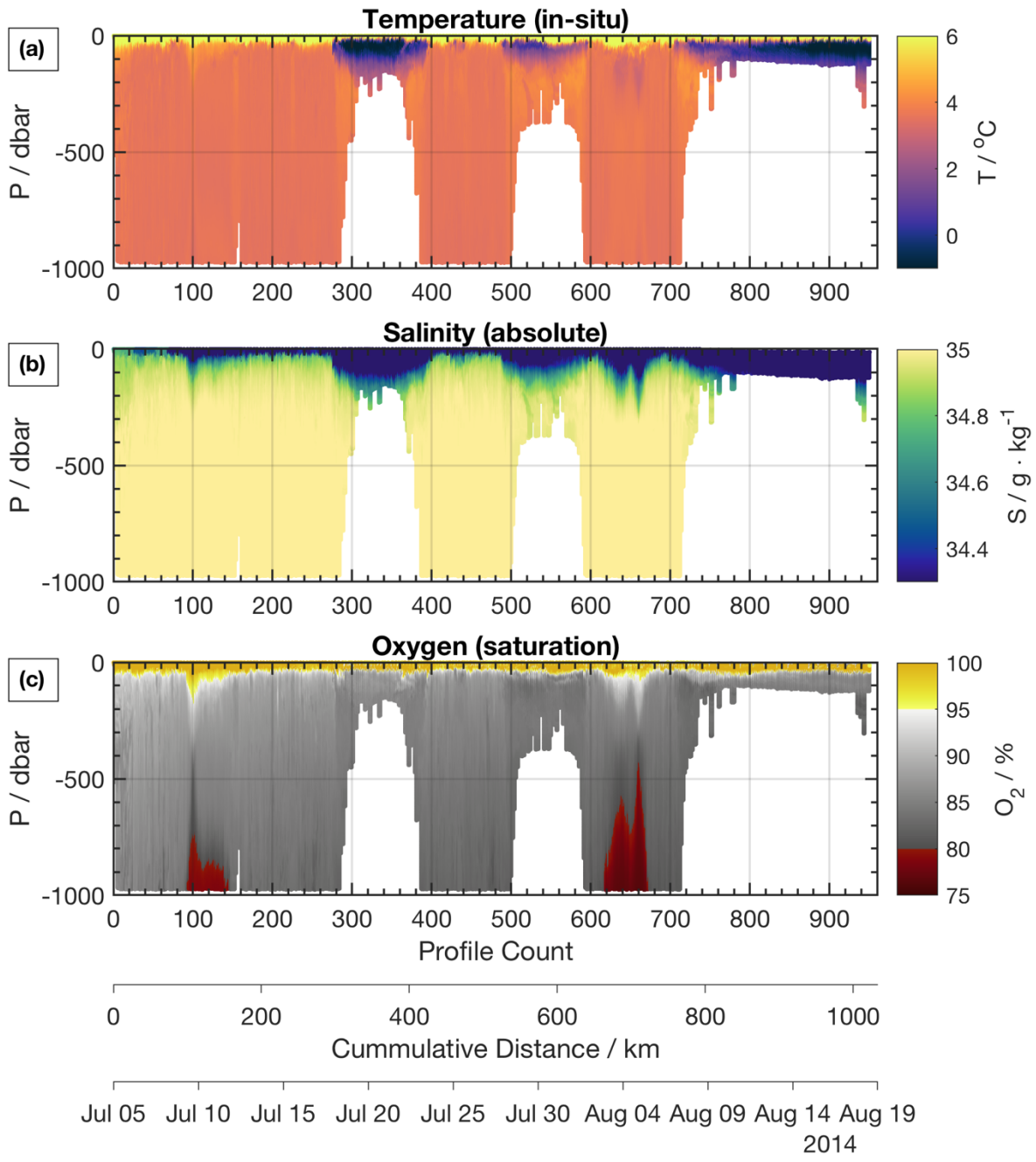

Figure 4.11.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.12 unit_473 Trinity Bay Mission 2014

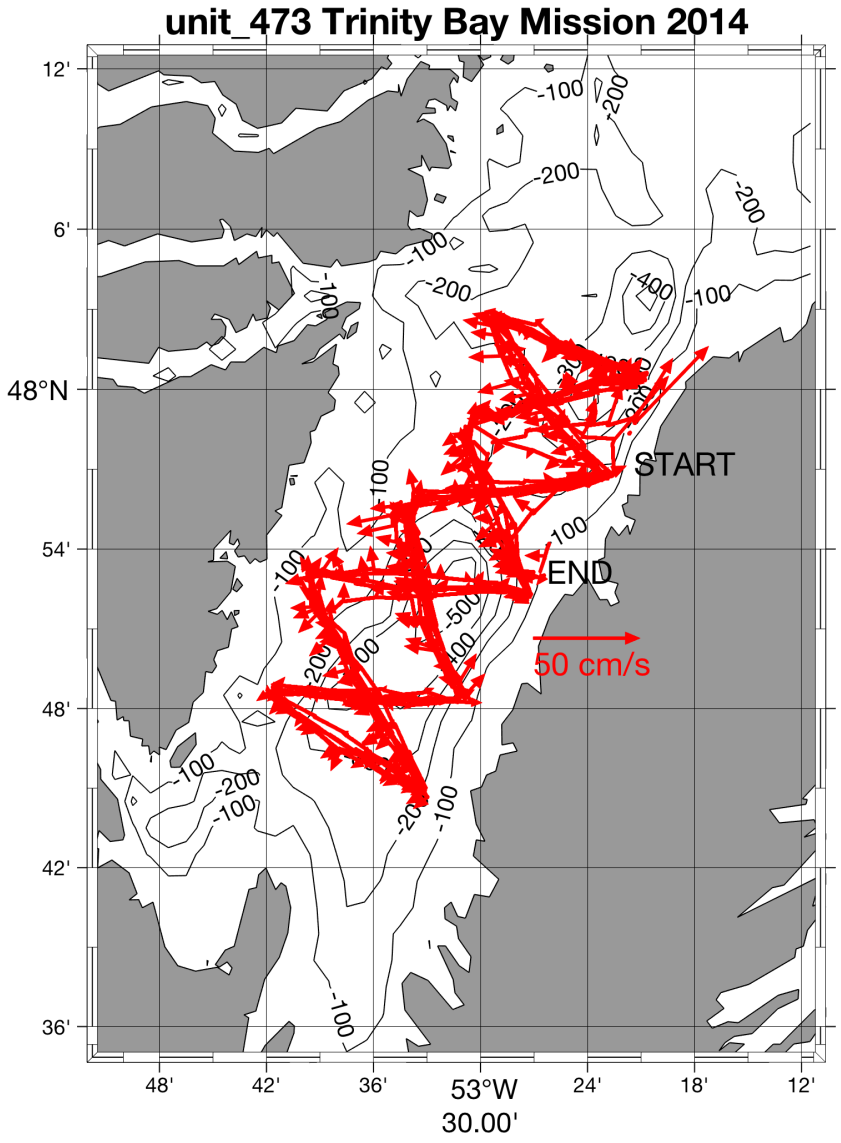

Figure 4.12.1. Deployment map of Trinity Bay Mission in 2014 for Glider Unit_473 to test sensors and glider, as well as compare data between platform (Unit_472) for calibration purposes.

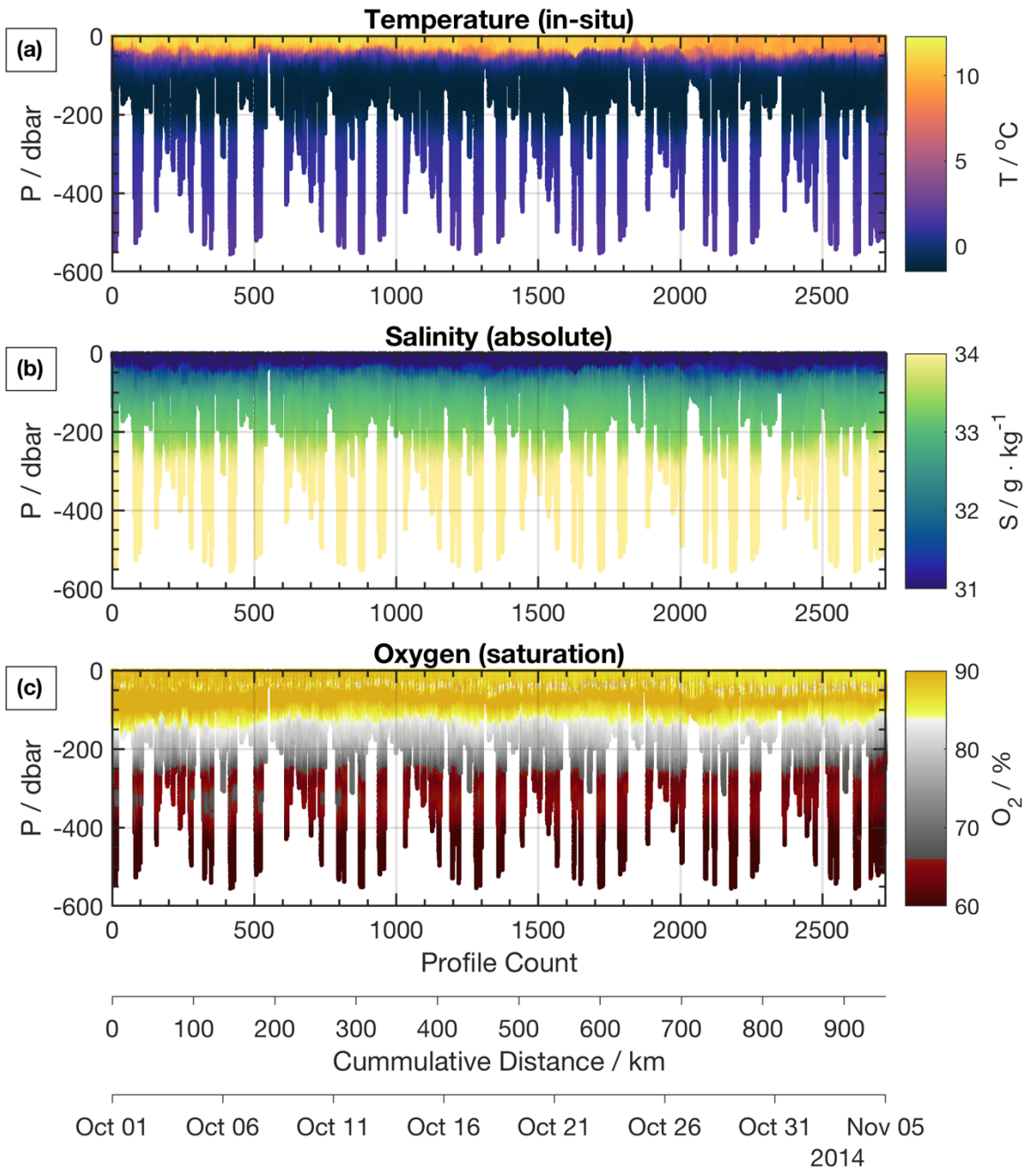

Figure 4.12.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.13 unit_472 Trinity Bay Mission 2014

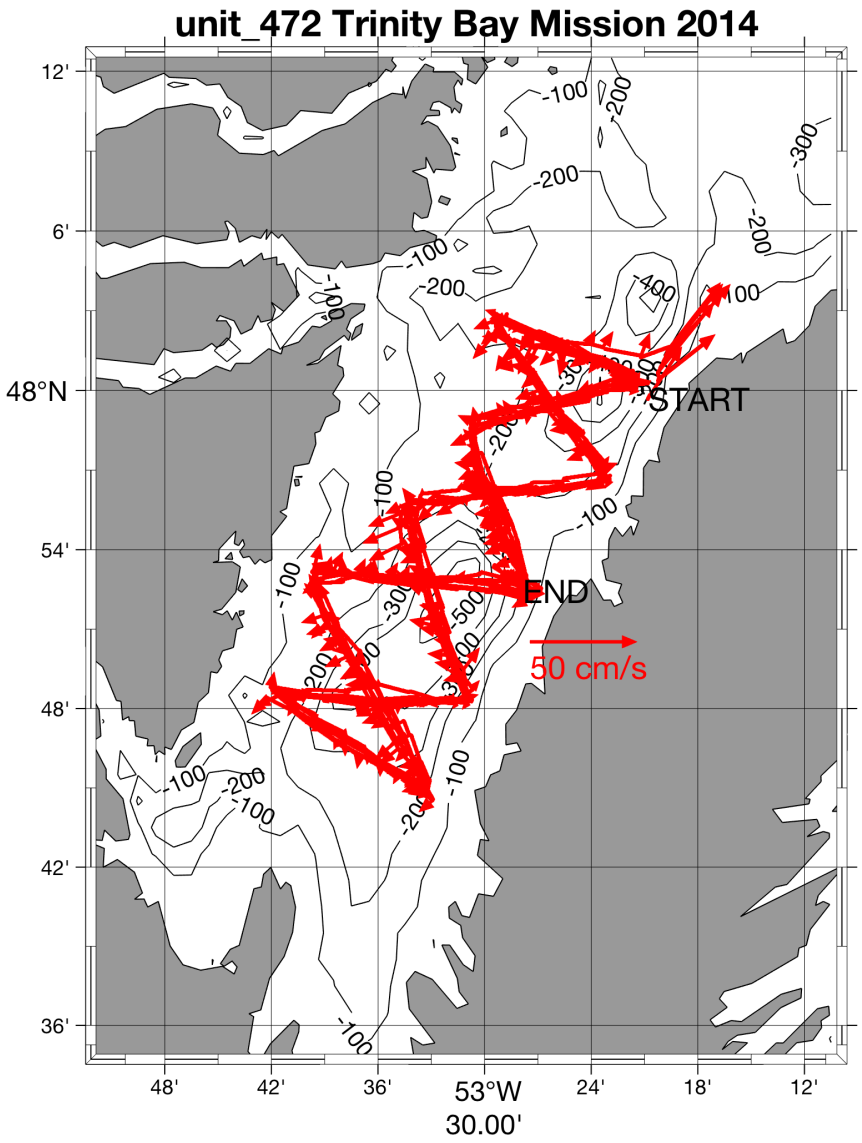

Figure 4.13.1. Deployment map of Trinity Bay Mission in 2014 for Glider Unit_472 to test sensors and glider, as well as compare data between platform (Unit_473) for calibration purposes.

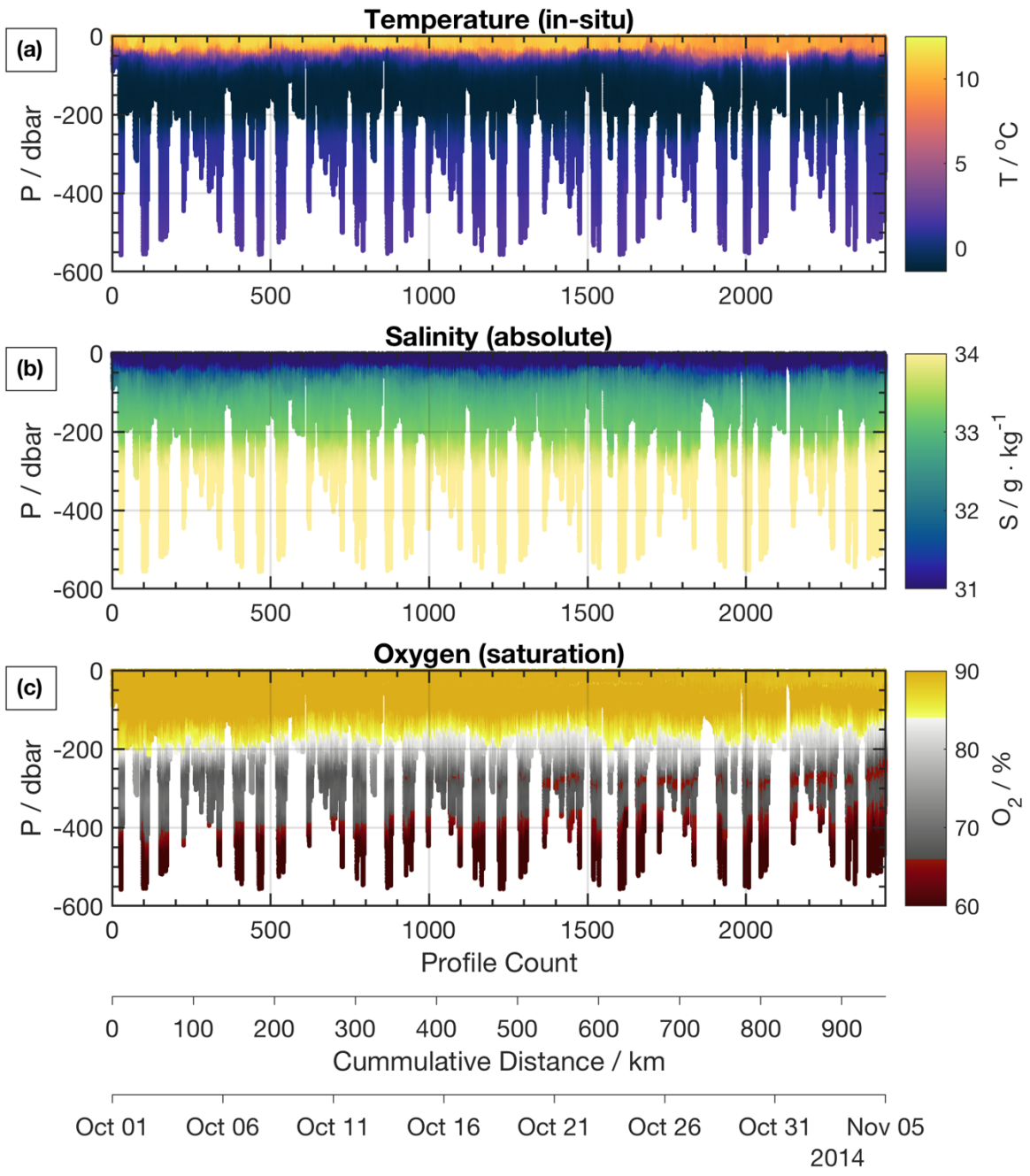

Figure 4.13.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.14 unit_472 Trinity Bay Mission 2015

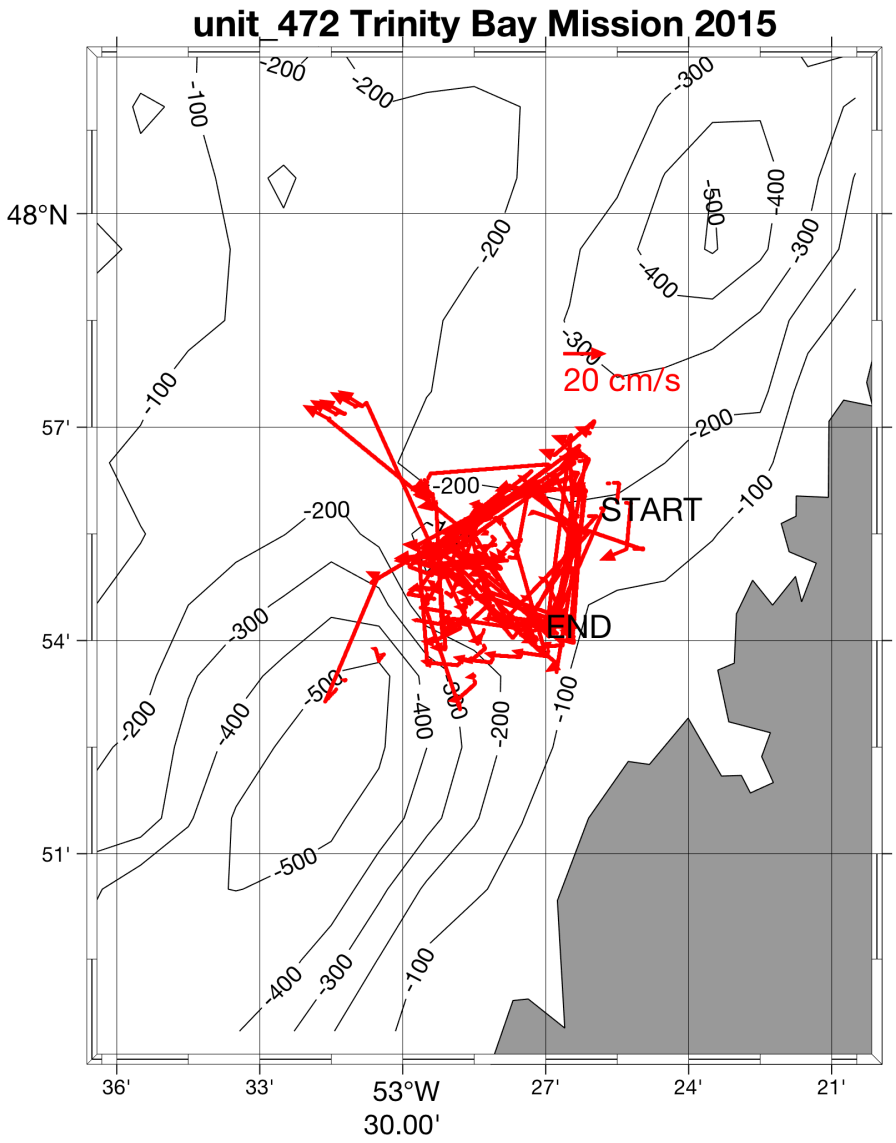

Figure 4.14.1. Deployment map of Trinity Bay Mission in 2015 for Glider Unit_472. Purpose of the deployment was to test the sensors and collect calibration data for the new pCO2 Optode.

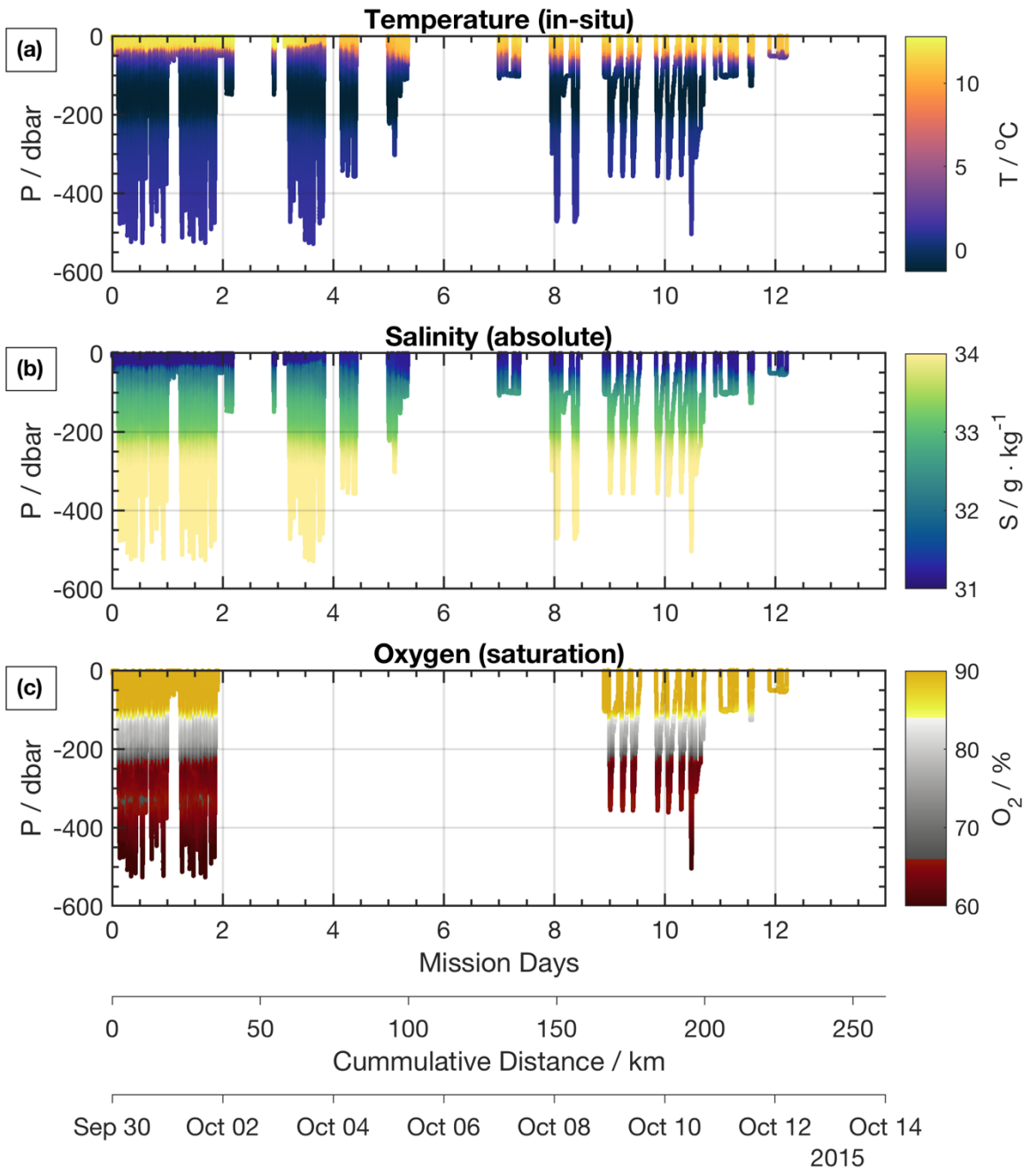

Figure 4.14.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of mission days. The time axis shows the length of deployment and is for scale.

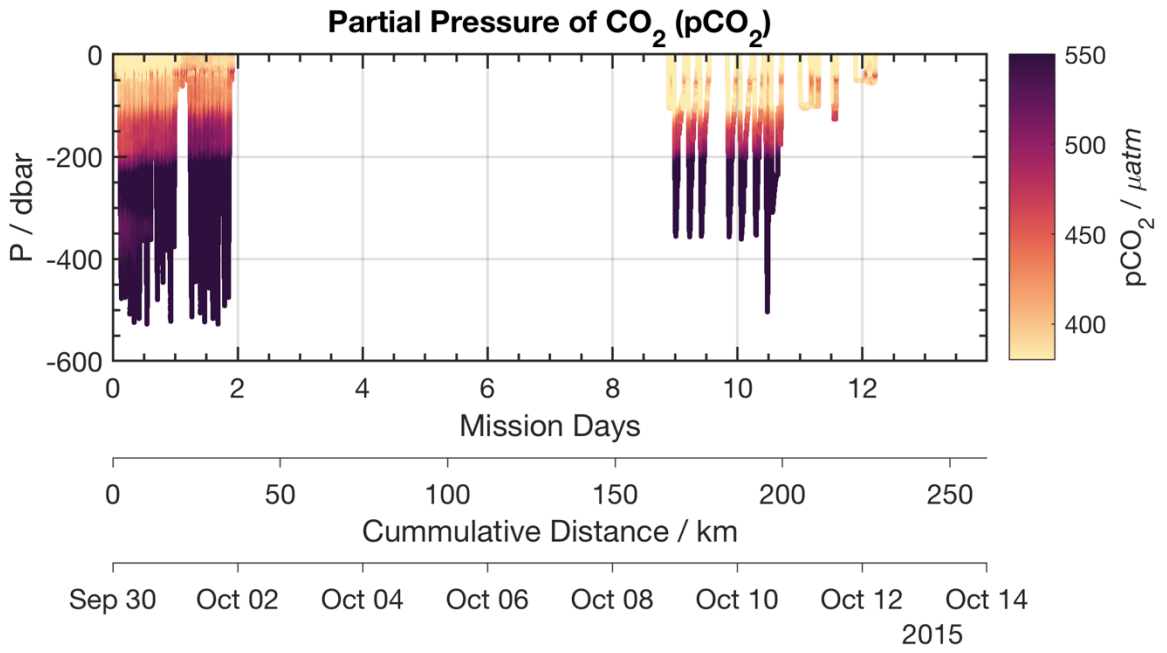

Figure 4.14.3. Collected prototype Aanderaa CO_2 Optode data from the deployment. Some basic corrections have been done to correct the data for conditioning and sensor lag, but the data are not validated. A basic surface correction has been applied to bring the data closer to the mean atmospheric CO_2 values in October 2015. This is the best performance of this sensor in the 3 glider deployments.

4.15 unit_473 Trinity Bay Mission 2016

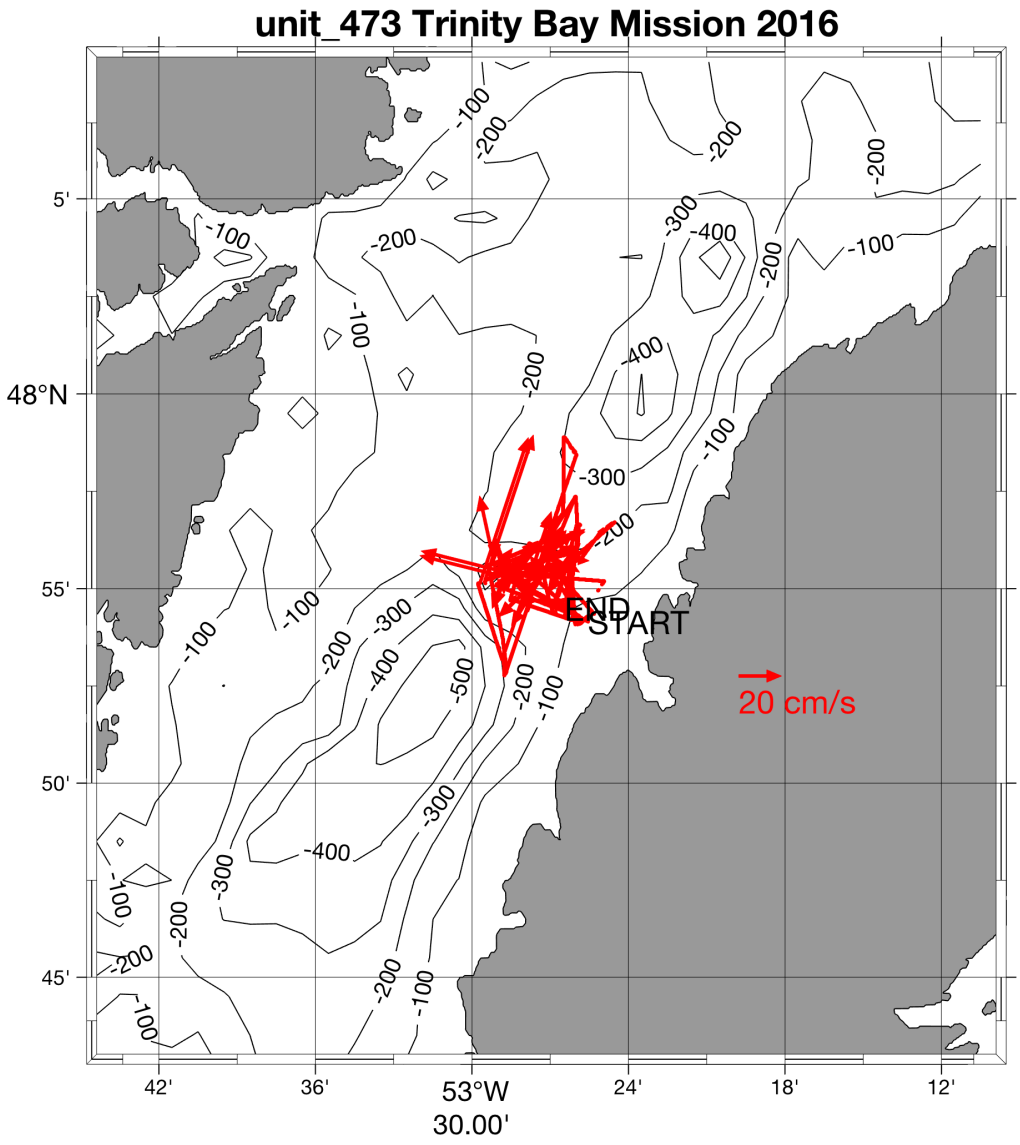

Figure 4.15.1. Deployment map of Trinity Bay Mission in 2016 for Glider Unit_473. Purpose of the deployment was to test the sensors and collect calibration data for the new pCO2 Optode.

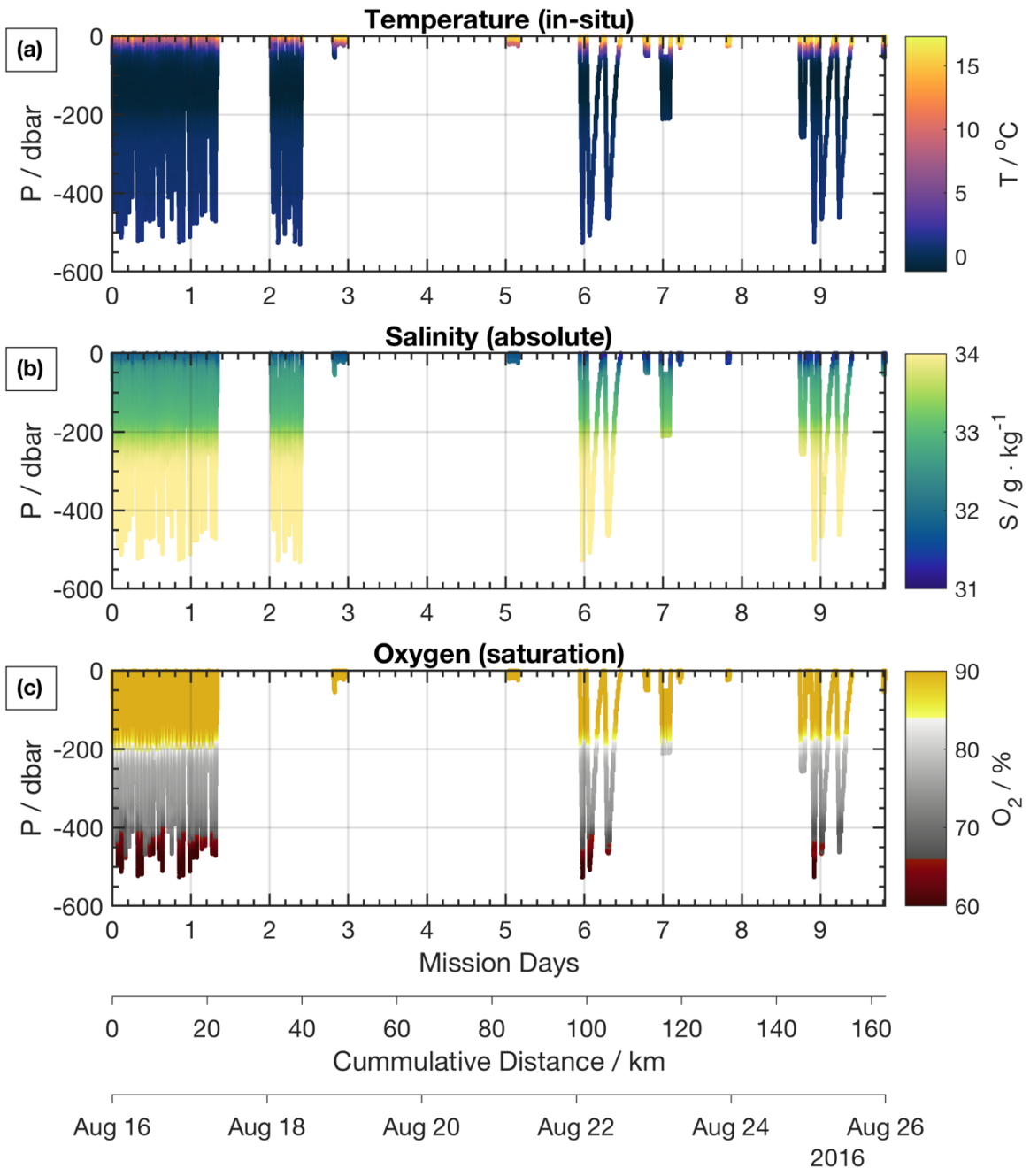

Figure 4.15.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of mission days. The time axis shows the length of deployment and is for scale.

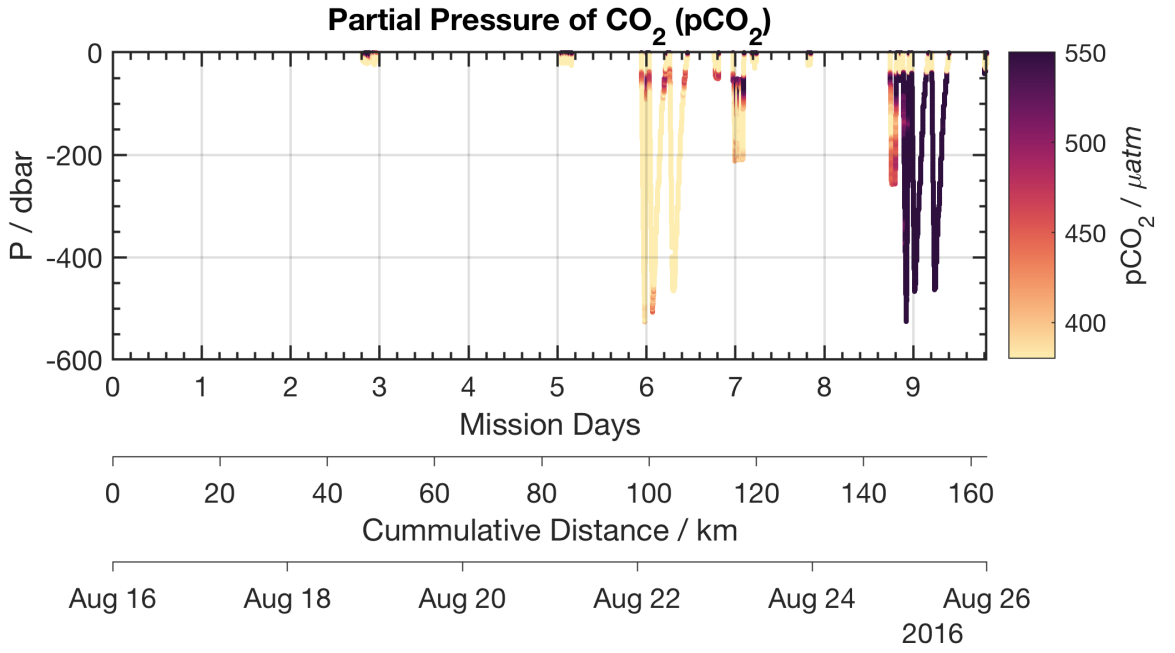

Figure 4.15.3. Collected prototype Aanderaa CO_2 Optode data from the deployment. Some basic corrections have been done to correct the data for conditioning and sensor lag, but the data are not validated. A basic surface correction has been applied to bring the data closer to the mean atmospheric CO_2 values in October 2016.

4.16 unit_473 Labrador Sea Mission 2016

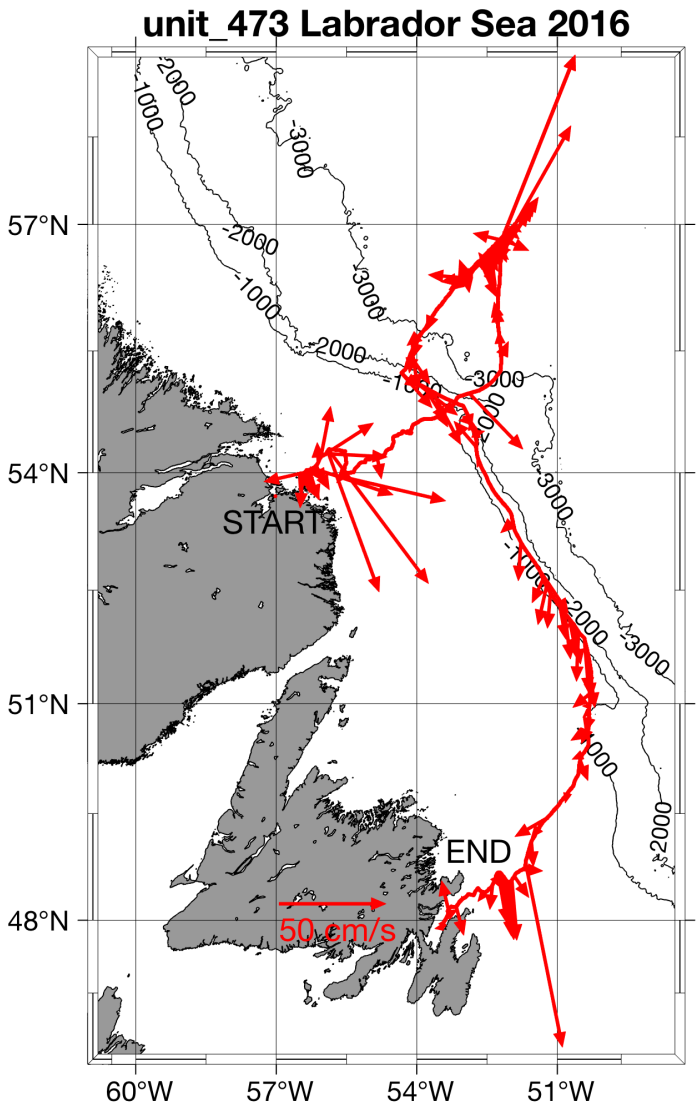

Figure 4.16.1.Deployment map of Labrador Shelf Mission in 2016 for Glider Unit_473, part of Ventilations, Interactions and Transports Across the Labrador Sea (VITALS) Program to capture glider-based CO_2 data near K1 Mooring in the central Labrador Sea.

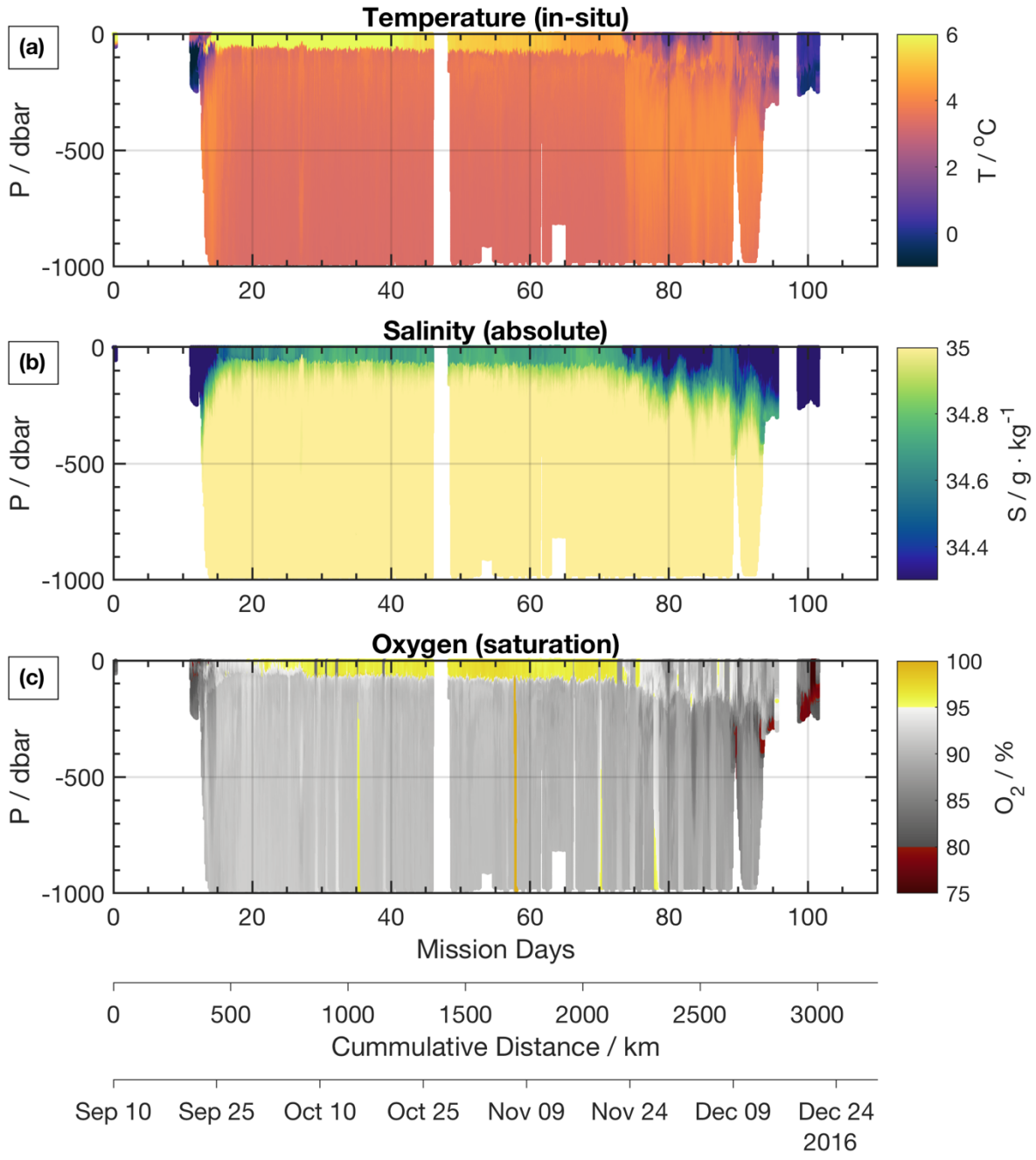

Figure 4.16.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of mission days. The time axis shows the length of deployment and is for scale. Column-like oxygen data from thruster use at depth.

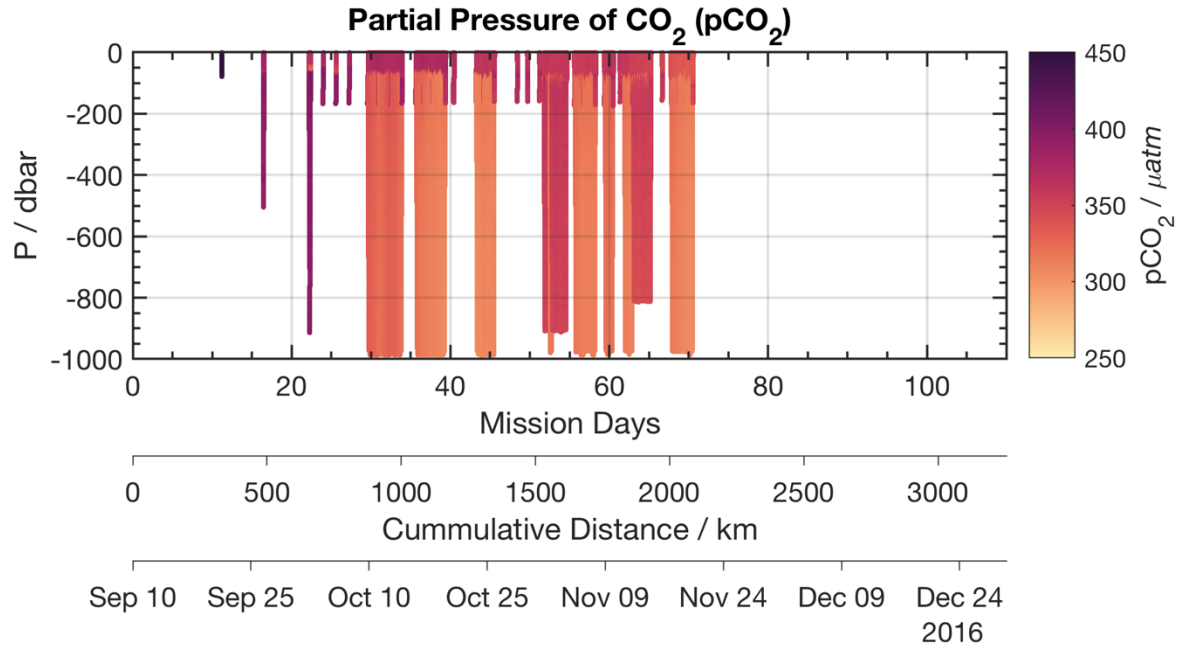

Figure 4.16.3. Collected prototype Aanderaa CO_2 Optode data from the deployment. Some basic corrections have been done to correct the data for conditioning and sensor lag, but the data are not validated. A basic surface correction has been applied to bring the data closer to the mean atmospheric CO_2 values in October 2016. Constant oxygen and CO_2 values with depth are artefacts are from the glider thruster.

4.17 unit_473 Trinity Bay Mission 2018

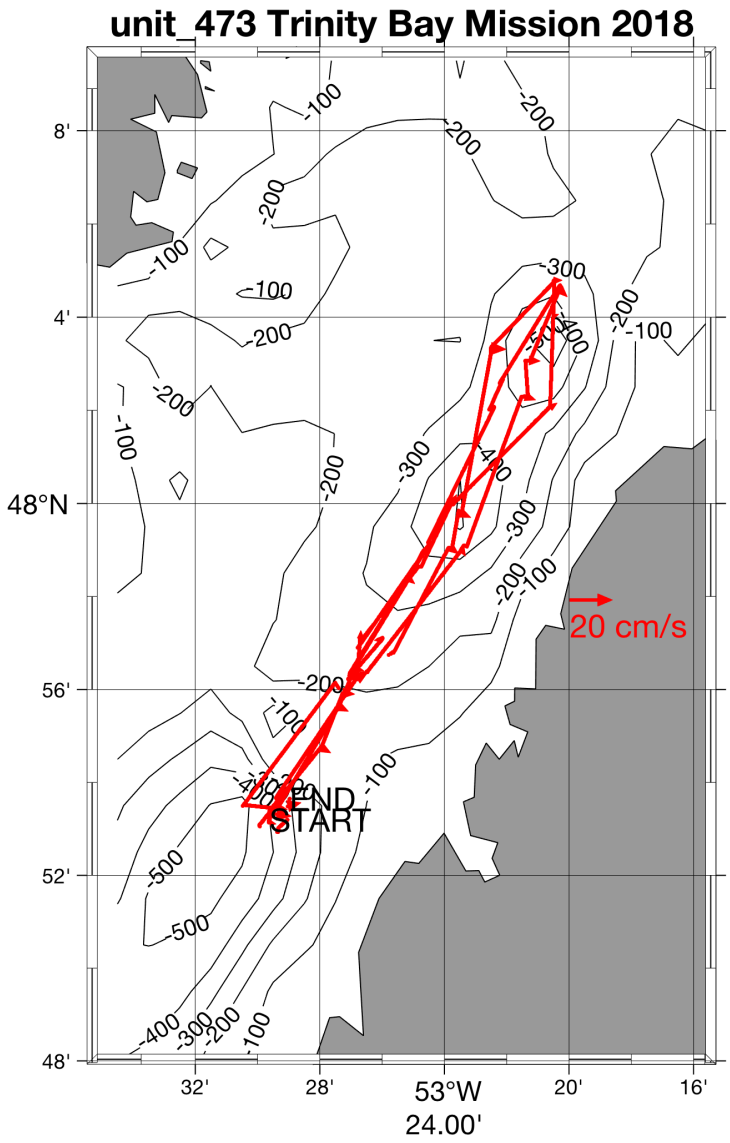

Figure 4.17.1. Deployment map of Trinity Bay 2018 Deployment for Glider Unit_473, part of Ventilations, Interactions and Transports Across the Labrador Sea (VITALS) Program. This was a verification test for the data collected during the previous 2016 Labrador Sea deployment.

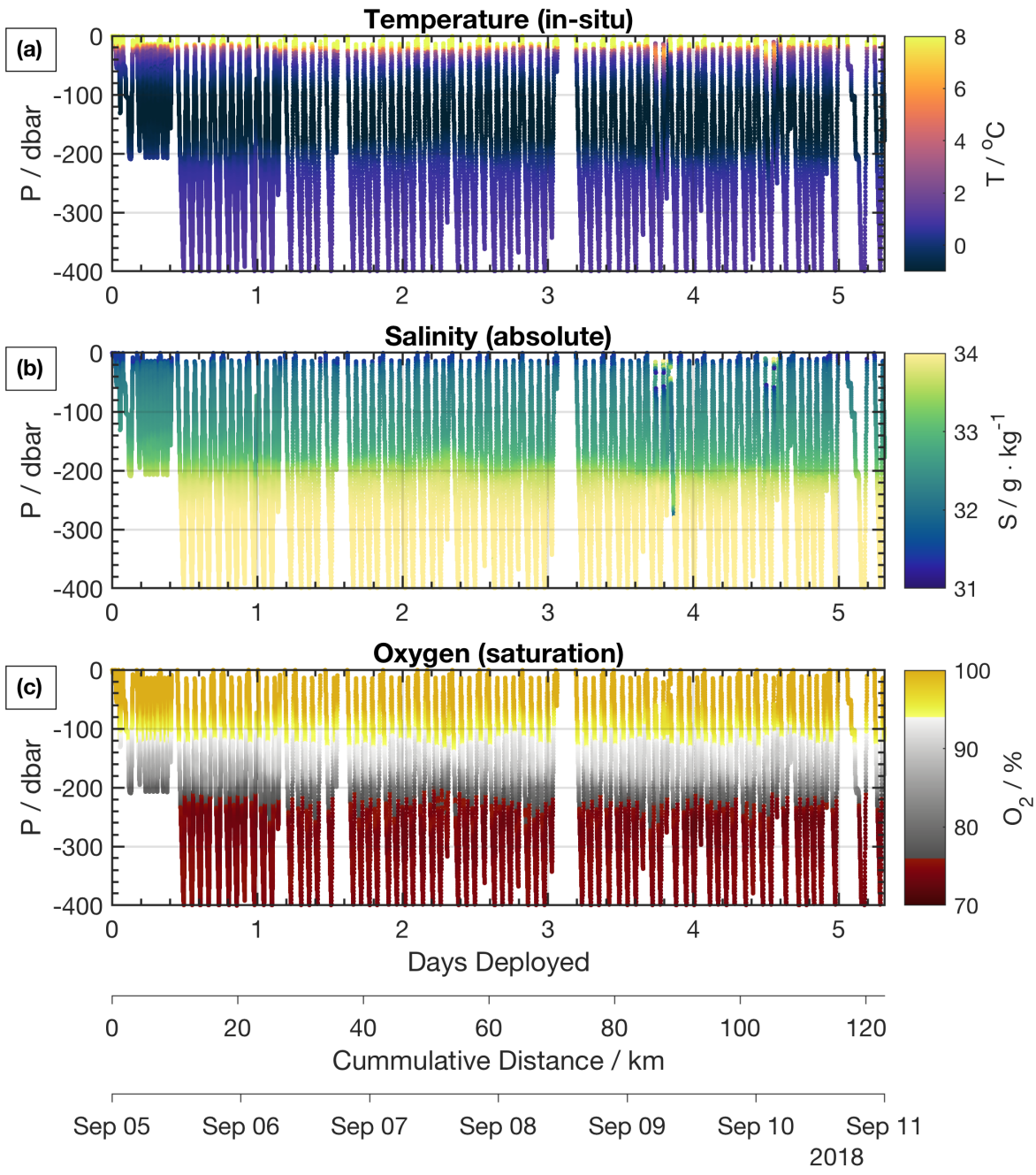

Figure 4.17.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of mission days. The time axis shows the length of deployment and is for scale.

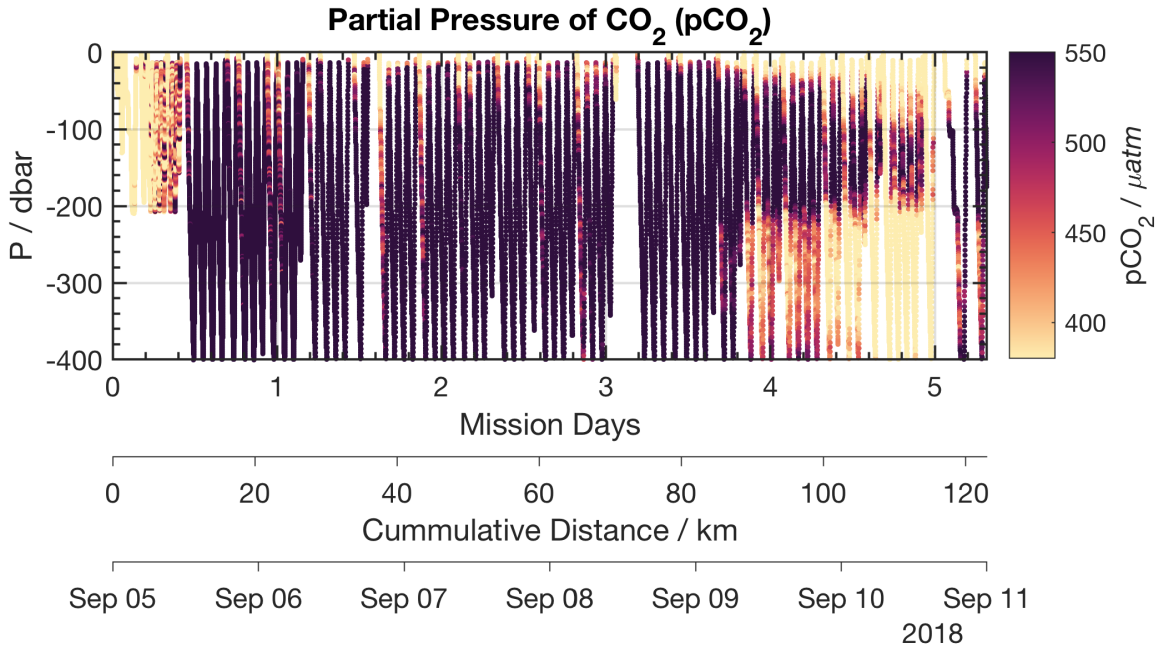

Figure 4.17.3. Collected prototype Aanderaa CO_2 Optode data from the deployment. Some basic corrections have been done to correct the data for conditioning and sensor lag, but the data are not validated. A basic surface correction has been applied to bring the data closer to the mean atmospheric CO_2 values in September 2018. The sensor likely malfunctioned, rendering this data set not useful for observations. It was used in a test to quantify the sensor performance for the previous 2016 Labrador Sea deployment.

4.18 unit_473 Bonne Bay Mission 2019

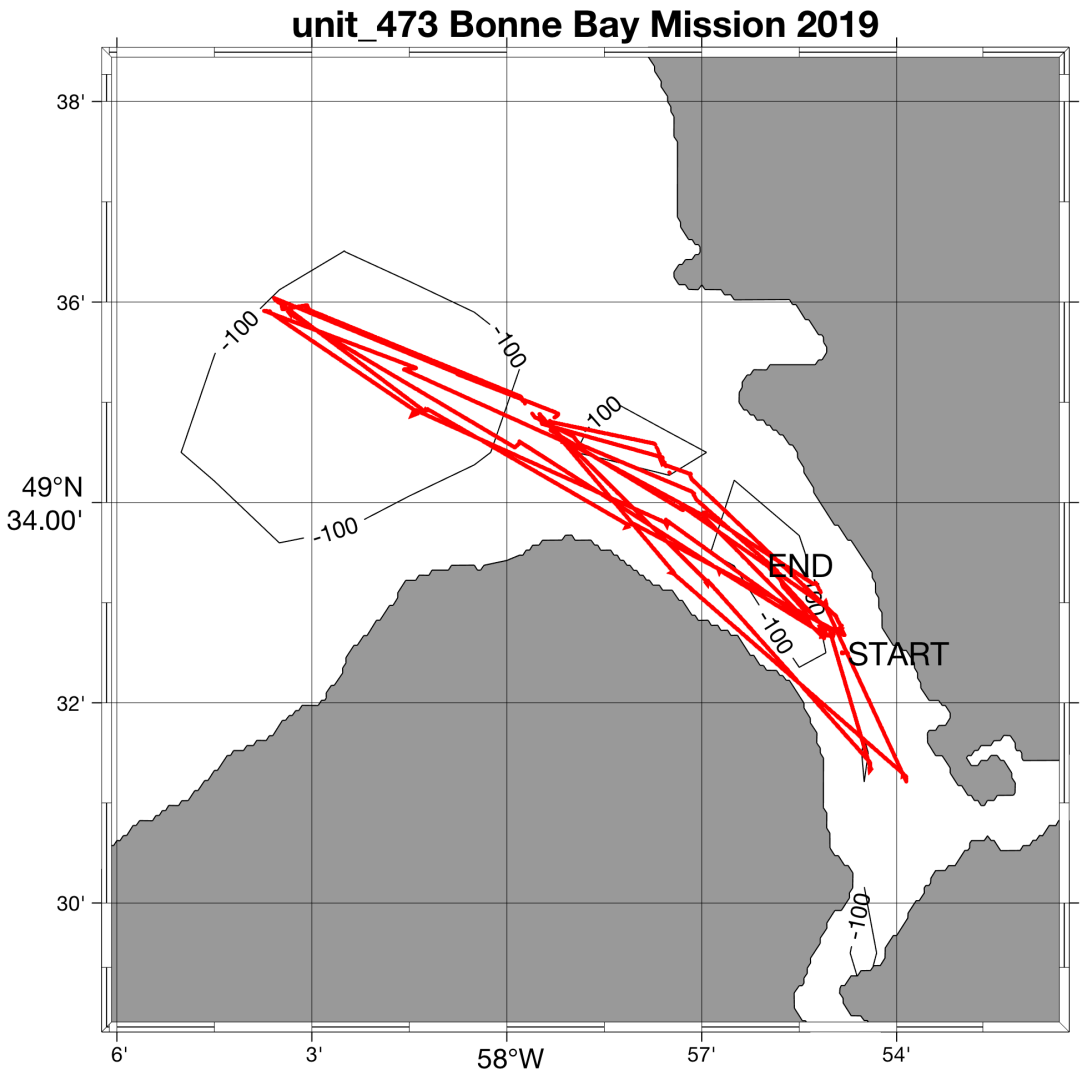

Figure 4.18.1. Deployment map for Bonne Bay 2019 deployment of Glider Unit_473 to study oxygen, heat and salt exchange in a tidal fjord in Newfoundland.

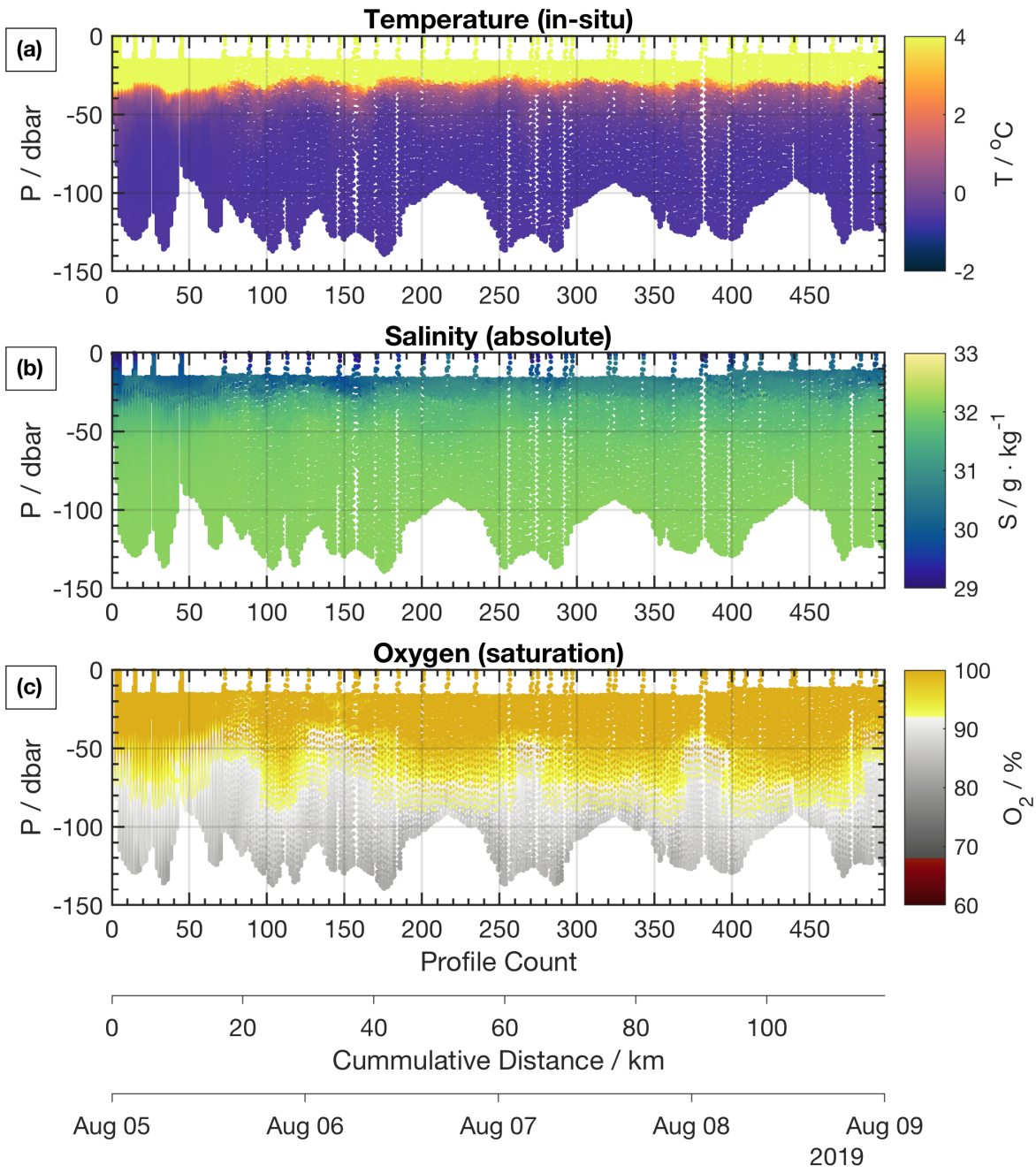

Figure 4.18.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.19 Pearldiver Gulf Mission 2019

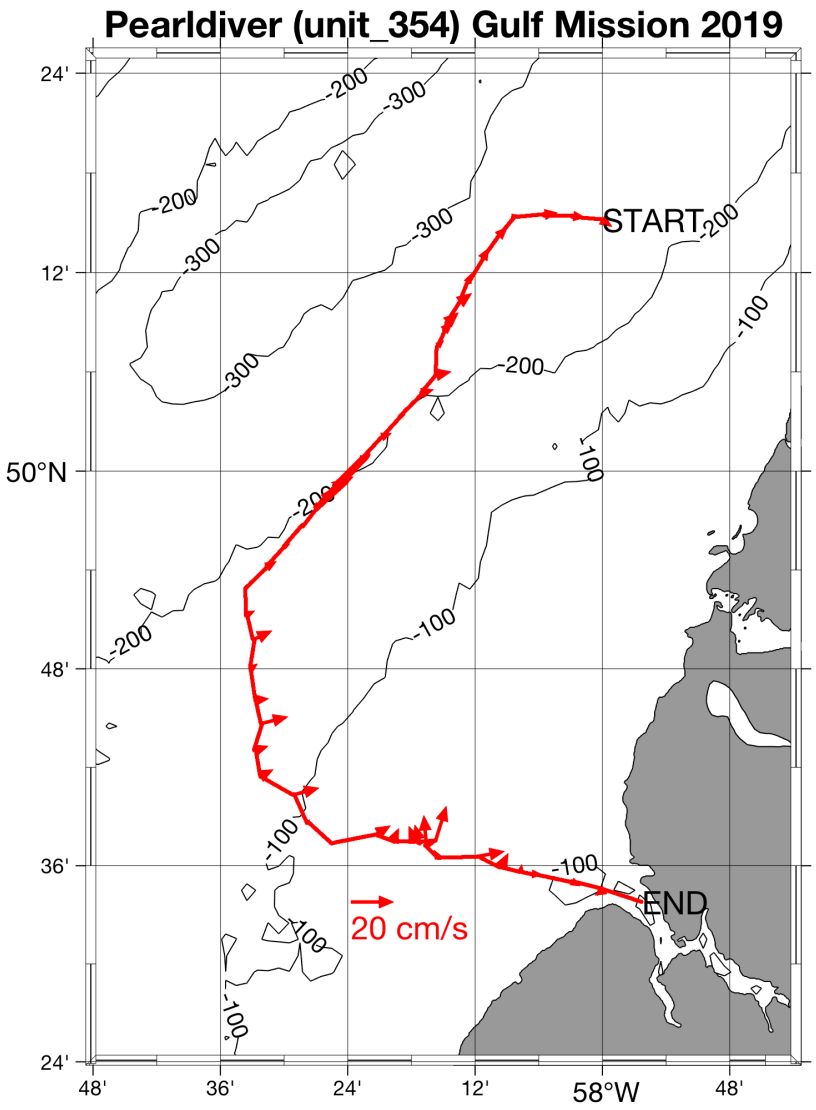

Figure 4.19.1. Deployment map of Pearldiver (ex. Unit_354) deployed in the Northern Gulf of St. Lawrence to study oxygen levels in Esquiman Channel.

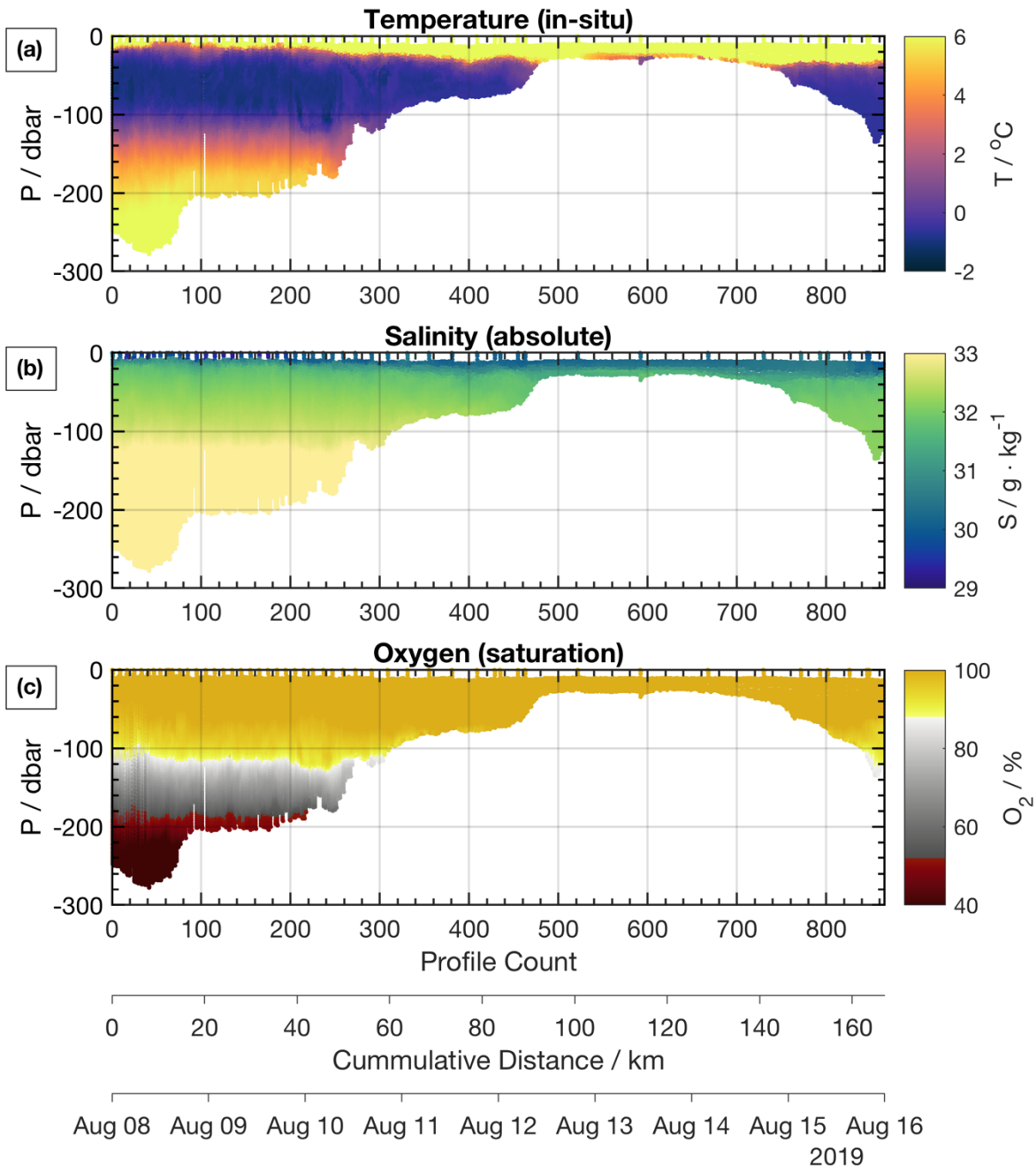

Figure 4.19.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

4.20 Pearldiver Labrador Sea Mission 2020

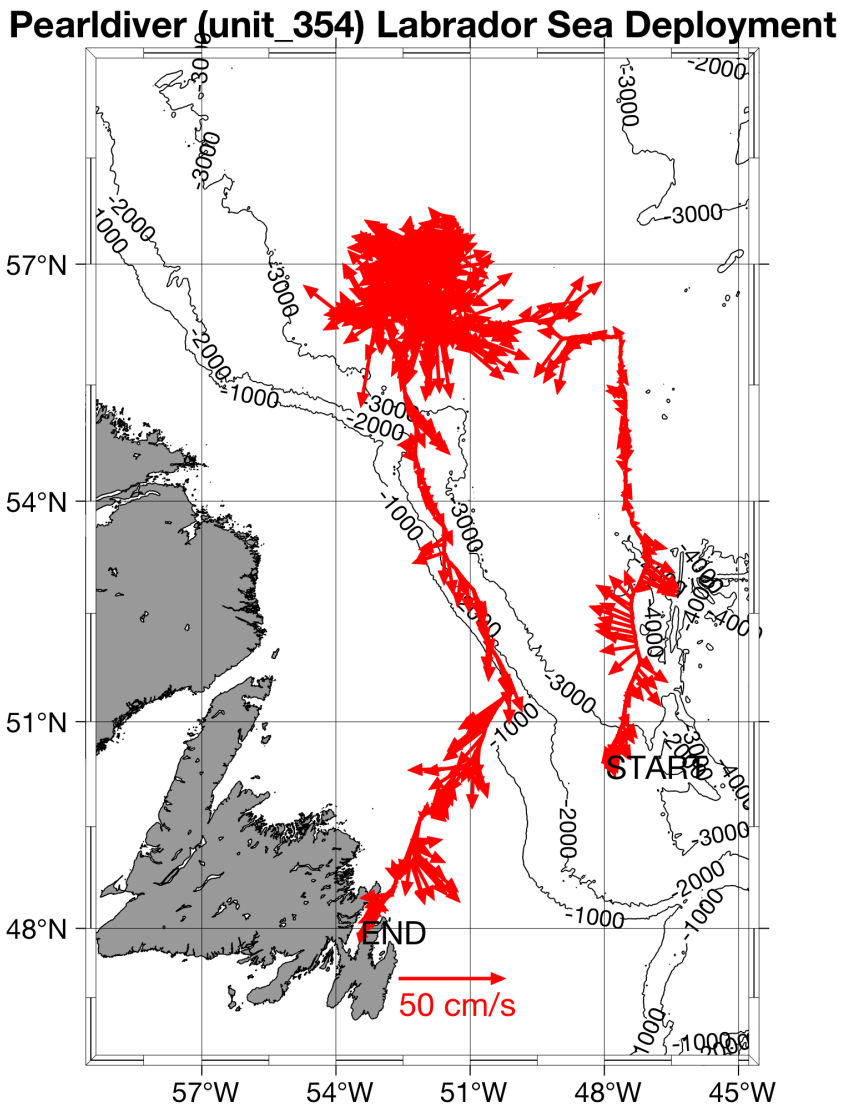

Figure 4.20.1. Deployment map of Pearldiver (ex. Unit_354) deployed in the Labrador Sea

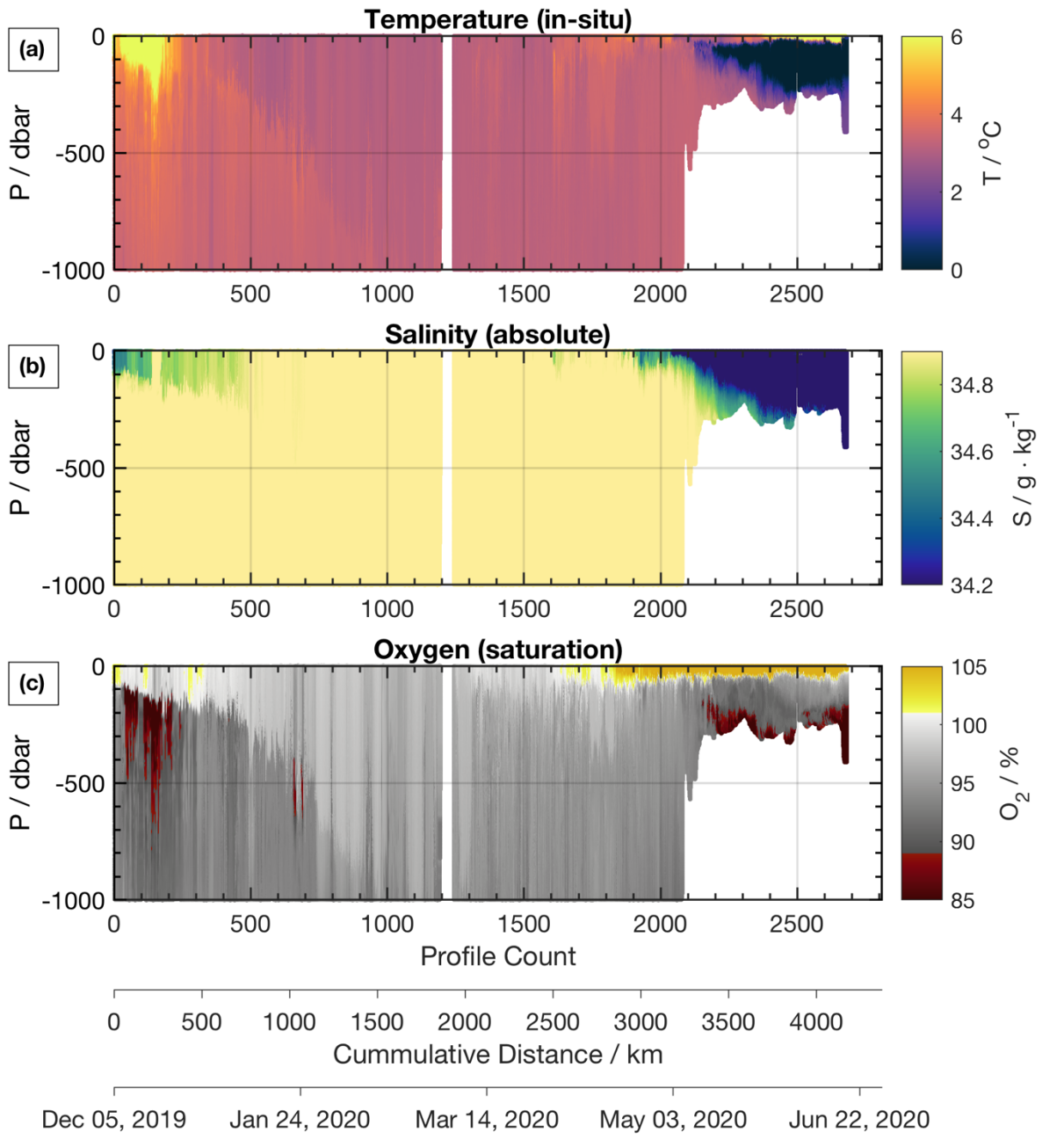

Figure 4.20.2. Collected hydrographic data (a) in-situ temperature, (b) absolute salinity and (c) oxygen saturation with respect to solubility calculated from the GSW toolbox. Axes are plotted over pressure and the number of completed yo profiles. The time axis shows the length of deployment and is for scale.

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