RV *Investigator* Voyage Scientific Highlights and Summary

Voyage #:	**IN2019_V02**		
Co-Voyage title:	SOTS: Southern Ocean Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania; Subantarctic Biogeochemistry of Carbon and Iron, Southern Ocean Time Series site		
Mobilisation:	Hobart, Tuesday - Wednesday, 12-13 March 2019		
Depart:	Hobart, Thursday, 14 March 08:00 for equipment tests in Storm Bay and then transit to SOTS site		
Return:	Hobart, Friday, 5 April 2019, 0800		
Demobilisation:	Hobart, Friday, 5 April 2019		
Voyage Manager:	Tegan Sime	Contact details:	Tegan.Sime@csiro.au
Chief Scientist:	Thomas W. Trull		
Affiliation:	CSIRO	Contact details:	Tom.Trull@csiro.au
Principal Investigators:	Philip Boyd (Shore based), Mathew Bressac (Sea going), Robert Strzepek (Sea Going).		
Project name:	Subantarctic Biogeochemistry of Carbon and Iron, Southern Ocean Time Series site		
Affiliation:	UTAS	Contact details:	Philip.Boyd@utas.edu.au

Scientific Highlights

The Chief Scientist

Professor Trull's expertise is in chemical oceanography and marine biogeochemistry, in particular the use of chemical, isotopic, and sensor measurements to trace material flows through microbial foodwebs.

He obtained a PhD from the Massachusetts Institute of Technology – Woods Hole Oceanographic Institution Joint Program in Oceanography in 1989, and after postdoctoral work at the University of Paris joined the Antarctic CRC in 1993, and CSIRO in 2013.

Key achievements include:

1. demonstration that artificial and natural iron fertilization can enhance particulate carbon flux to the ocean interior, but that this capacity is limited, and the risks insufficiently understood to merit largescale fertilization. This work contributed to the establishment of the International Maritime Organization moratorium on marine geo-engineering, for activities other than research.

2. contributions to understanding the status and progress of ocean acidification in Southern Ocean, Australian and Antarctic waters.

3. establishment of the Southern Ocean Time Series examining air-sea exchanges of heat and carbon dioxide, ocean productivity, and ecosystem structure and dynamics.

Title

SOTS: Southern Ocean Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania;

Subantarctic Biogeochemistry of Carbon and Iron, Southern Ocean Time Series site

Purpose

The voyage consisted of two projects that completed the following objectives:

1. The Southern Ocean Time Series deployed a new set of moorings and recovered the existing moorings. The SAZ sediment trap mooring collects samples to quantify the production and transfer of carbon and other nutrients to the ocean interior by sinking particles, and investigate their ecological controls. The Southern Ocean Flux Station (SOFS) mooring measures meteorological and ocean properties important to air-sea exchanges, ocean stratification, waves, currents, biological productivity and ecosystem structure. In addition the moorings, collect water samples for more detailed investigations of nutrient and plankton characteristics.

2. Trace elements: Measure profiles of trace element dissolved and particulate concentrations, and to examine the processes that produce and recycle them. The work contributes to a multi-year effort to deliver observations from 3 successive years and thus contribute to defining the stability versus interannual variability in trace element levels.

Contribution to the nation

The SOTS research improves understanding of the global climate system by focussing on a key region –the Southern Ocean. Careful sustained observations over the last decade and into the next increases our knowledge of how the ocean interacts with the atmosphere. Improved understanding is essential to enhance advice to the nation on climate variability affecting us now, develop future scenarios and impact assessments, and to make optimal decisions that will affect the nation's future. The work also directly addresses the issue of how ocean biogeochemistry and productivity respond to ocean dynamics, which is an important input to projecting future biogeochemical and ecosystem states. In addition, enhanced understanding of process occurring in the region related to clouds, ocean mixing, waves and rain will also lead to improved forecasts and warnings issued to the public.

As a result of this voyage, we have re-deployed the Southern Ocean Time Series moored platforms to provide an integrated and ongoing assessment of the seasonality of the processes that control air-sea exchanges important to climate, and upper ocean processes important to Subantarctic productivity. This analysis extends from the physics of ocean mixing and insolation, to the chemistry of ocean nutrients and the biological responses of phytoplankton, zooplankton and fish. Many of the observations are available in real-time via the internet (www.imos.org.au).

Voyage Summary

Scientific objectives

Trull: Southern Ocean Time Series

The Southern Ocean has a predominant role in the movement of heat and carbon dioxide into the ocean interior moderating Earth's average surface climate. SOTS uses a set of two automated moorings to measure these processes under extreme conditions, where they are most intense and have been least studied. The atmosphere-ocean exchanges occur on many timescales, from daily insolation cycles to ocean basin decadal oscillations and thus high frequency observations sustained over many years are required. The current context of anthropogenic forcing of rapid climate change adds urgency to the work.

The primary objective is to first deploy a new set of SOTS moorings (SOFS-8 and SAZ-21) and then recover the existing SOTS moorings (SOFS-7.5 and SAZ-20). Each of the SOTS moorings delivers to specific aspects of the atmosphere-ocean exchanges:

- the SAZ sediment trap mooring collects samples to quantify the transfer of carbon and other nutrients to the ocean interior by sinking particles and investigate their ecological controls.
- the Southern Ocean Flux Station (SOFS) mooring measures meteorological and ocean properties important to air-sea exchanges, ocean stratification, waves, and currents. Additional sensors quantify CO_2 partial pressure, net community production from oxygen and total dissolved gases and nitrate depletion, biomass from bio-optics and bio-acoustics. Water samples are collected for nutrient and plankton measurements after recovery.

Ancillary work will obtain supporting information on atmospheric and oceanographic conditions using CTD casts for samples and bio-optical sensor data, underway measurements, Triaxus towed body, Continuous Plankton Recorder and autonomous profiling Biogeochemical-Argo floats.

The final and lowest priority SOTS objectives, for the purposes of furthering engineering analyses and cleaning up the SOTS site, are to: i) to recover the lower section of the SOFS-6 mooring (which broke at ~1800 m below the surface) and ii) deploy a test anchor equipped with a package of high engineering sensors which will be released and recovered.

Boyd: Subantarctic Biogeochemistry of Carbon and Iron, Southern Ocean Time Series site

The subantarctic water mass forms a circumpolar ring which comprises half of the open waters of the Southern Ocean. Complex environmental forcing controls its productivity, ecology and biogeochemistry both in the present day and in the geological past. An improved mechanistic understanding of these controls on the marine biota is needed, and will provide the context to better interpret observations being obtained at unparalleled resolution by the SOTS moorings. Our study will forge strong links with SOTS by determining how environmental forcing manifests itself in biological and biogeochemical signatures across a range of scales. A better understanding of this relationship will aid the development of a state-of-the-art coupled iron and carbon biogeochemical model which will be validated using future multi-property time-series observations.

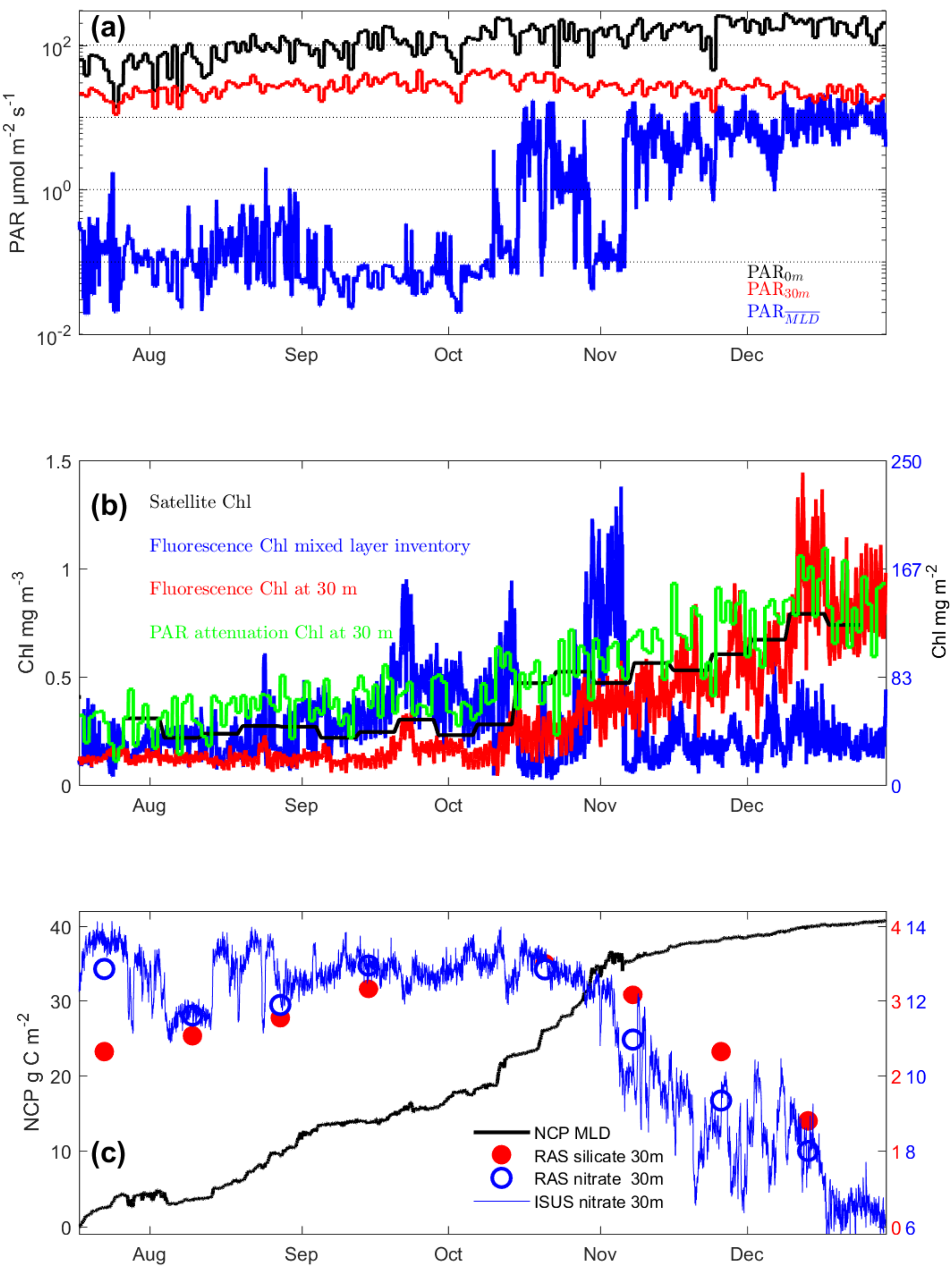
Our main aim is to enhance our understanding of the interlinked biogeochemical cycles of iron and carbon in the Southern Ocean to better understand how intra-seasonal, seasonal and interannual variability in iron supply and recycling influences the productivity and export of carbon into the ocean's interior in the subantarctic circumpolar ring. Additional aims include:

- Elucidation of the relative roles of iron supply versus biological and photochemical recycling in driving subantarctic primary productivity and export fluxes.
- Resolution of the interplay of multiple environmental controls – irradiance, mixed layer depth, trace element supply (zinc, copper, etc.), silicate supply, iron availability – across a range of temporal and spatial scales – to better predict changes in rates of primary productivity.
- Enhancement of knowledge on the interplay of mesoscale and sub mesoscale physics and biogeochemistry in the vicinity of the SOTS site to better understand the degree of coupling and integration of surface ocean processes with those in the subsurface ocean (such as the sensors and particle traps on the SOTS mooring).

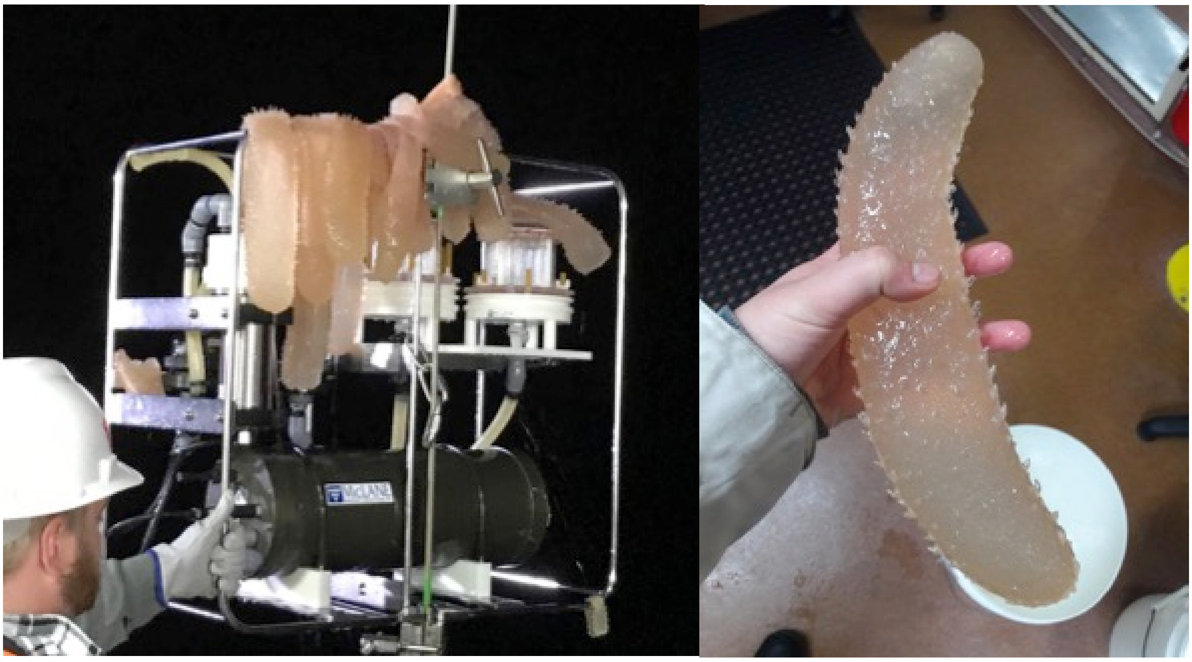
Results

The SOTS program achieved its primary goals: the moorings were successfully recovered and replaced. This builds our overall understanding of climate and carbon cycle processes in Subantarctic waters, which is now recognized as a globally important region of removal of CO2 from the atmosphere.

In our 2018 Voyage Report, we provided a synthesis of the strong seasonal physical variations that occur including high winds, waves, insolation, and air-sea heat fluxes and the deep mixing that they drive in winter, following by stratification in spring. This year we showcase biological responses, which exhibit surprisingly high total water column chlorophyll in winter that precedes the development of ocean stratification to springtime warming. Our sensors deliver estimates of both states and rates of biological activity, including two in-situ measures of phytoplankton biomass (from the chlorophyll fluorescence sensor and the attenuation of photosynthetically available radiation, PAR, measured at 29m depth compared to the surface) and their rates of net community production (NCP, obtained by combining results from oxygen and total gas sensors) and associated nutrient consumption (from an ultra-violet spectrometric nitrate sensor and the RAS water samples. The high winter biomass is shown by the blue line in panel (b) which provides the phytoplankton biomass inventory from the surface to the bottom of the mixed layer, and the associated net community production by the black line in panel (c).


(a)
PAR µmol m-2 s-1
10^2
10^0
10^-2
PAR0m
PAR30m
PARMLD
Aug
Sep
Oct
Nov
Dec
(b)
Satellite Chl
Fluorescence Chl mixed layer inventory
Fluorescence Chl at 30 m
PAR attenuation Chl at 30 m
Chl mg m-3
Chl mg m-2
1.5
1
0.5
0
250
167
83
0
Aug
Sep
Oct
Nov
Dec
(c)
NCP g C m-2
40
30
20
10
0
4 14
3 12
2 10
1 8
0 6
NCP MLD
RAS silicate 30m
RAS nitrate 30m
ISUS nitrate 30m
Aug
Sep
Oct
Nov
Dec

As a scientific highlight from the zooplankton group, a bloom of pyrosomes (Tunicata, Chordata) was observed interfered during voyage IN2019_V02. Due to their high abundance they interfered with the Triaxus tows, CTD sensors and were collected on the In-situ pumps (ISPs). Especially in the night of the 28/03/19, many pyrosomes of the species *Pyrosoma atlanticum* were observed around the ship, many of them glowing due to bioluminescence. Not much is known about the influence of pyrosomes on the subantarctic carbon cycle or their biology, so this voyage was a unique opportunity to study their size distribution, cell structure and decomposition rate and collect samples for lipid and carbon measurements. For more information, contact: Svenja.Halfter@utas.edu.au.



Pyrosomes on the In-situ pump (left, photo: Phil Butterworth) and caught by the Bongo net (right, photo: Svenja Halfter)

Observed deep mixing from an autumn storm

One of the voyage highlights from the bio-optics perspective was the opportunity to observe profiles of physical, chemical and biological indicators both during a well-stratified period and after a mixing event due to a severe storm. One of the tricky aspects of interpreting profiles of phytoplankton fluorescence is the occurrence of deep fluorescence maxima that can be “real” chlorophyll maxima, i.e. due to increased biomass and/or increased chlorophyll per cell at depth, or they can be the result of non-photochemical quenching (NPQ) which reduces the fluorescence per chlorophyll at high light, i.e. near the surface of the ocean during daytime. Telling the two kinds of fluorescence maxima apart is not always an easy task, and getting a number of profiles that show both “real” and NPQ-induced deep fluorescence maxima was a treat on this voyage. During the calm period before the storm we encountered some “real” deep chlorophyll maxima that were also evident in the transmissometer data and persisted at night (see Figure 1, CTD 8). After the storm, the water column was well mixed, and the deep chlorophyll maximum was absent in the night data (Figure 2, CTD 22). However, the corresponding daytime data showed an NPQ-induced deep fluorescence maximum that is not evident in the transmissometer data (Figure 3, CTD 21). These sorts of observations will help us train algorithms that detect NPQ.

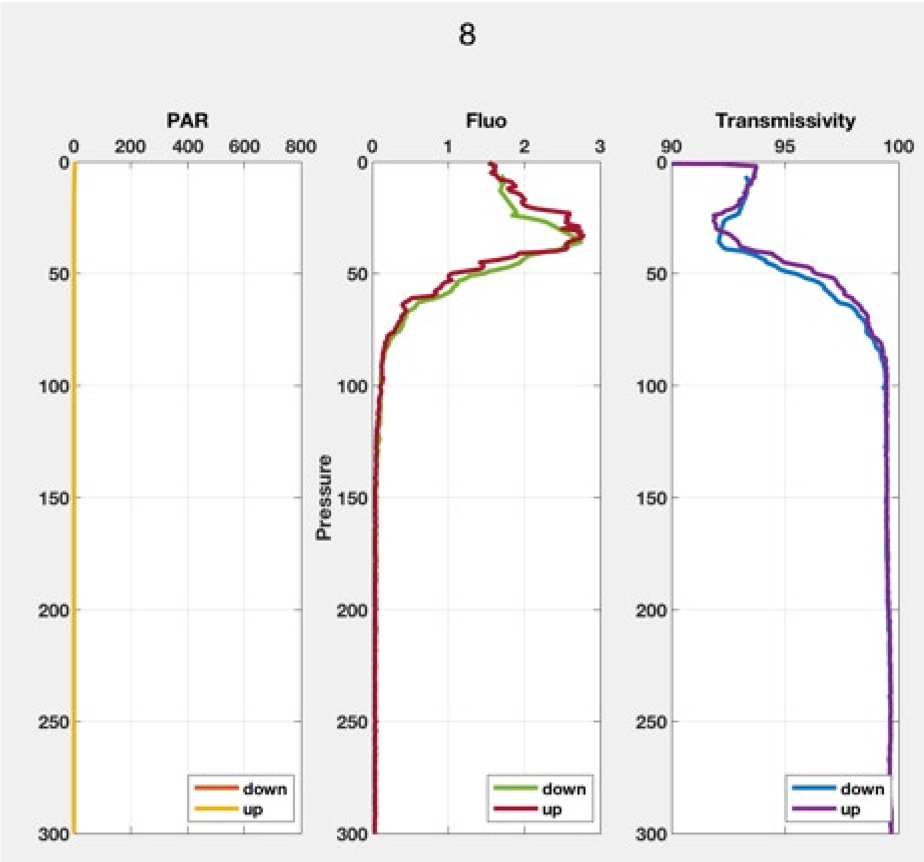


Figure 1: Incident light (PAR), fluorescence (Fluo) and transmissivity for CTD 8 before the storm. Different trace colours distinguish upcasts from downcasts. Note that this was a night cast and that transmissivity mirrors the fluorescence traces, hence this was likely a real deep chlorophyll maximum.

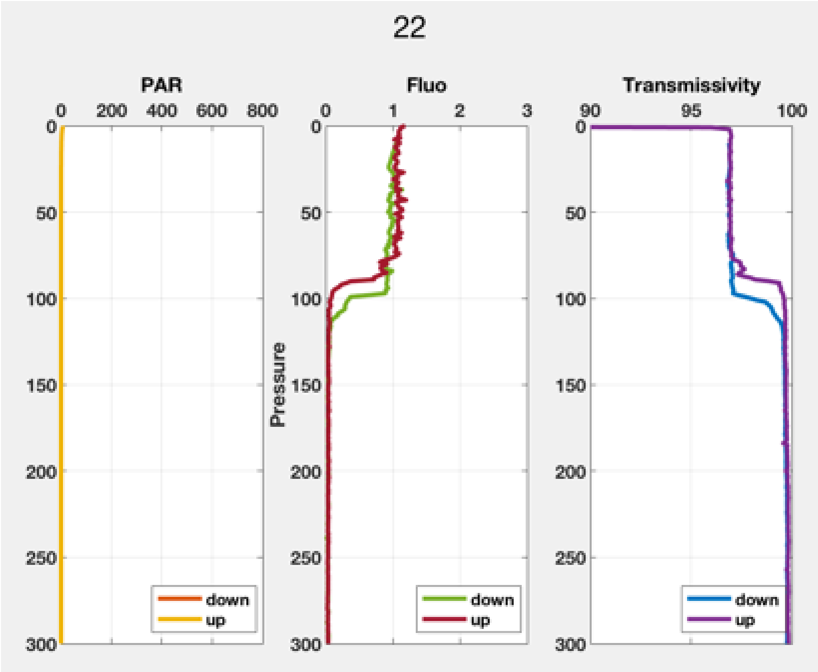


Figure 2: Incident light (PAR), fluorescence (Fluo) and transmissivity for CTD 22 after the storm. Different trace colours distinguish upcasts from downcasts. Note that this was a night cast and that transmissivity mirrors the fluorescence traces, both showing a well-mixed surface layer that reaches to ~90m.

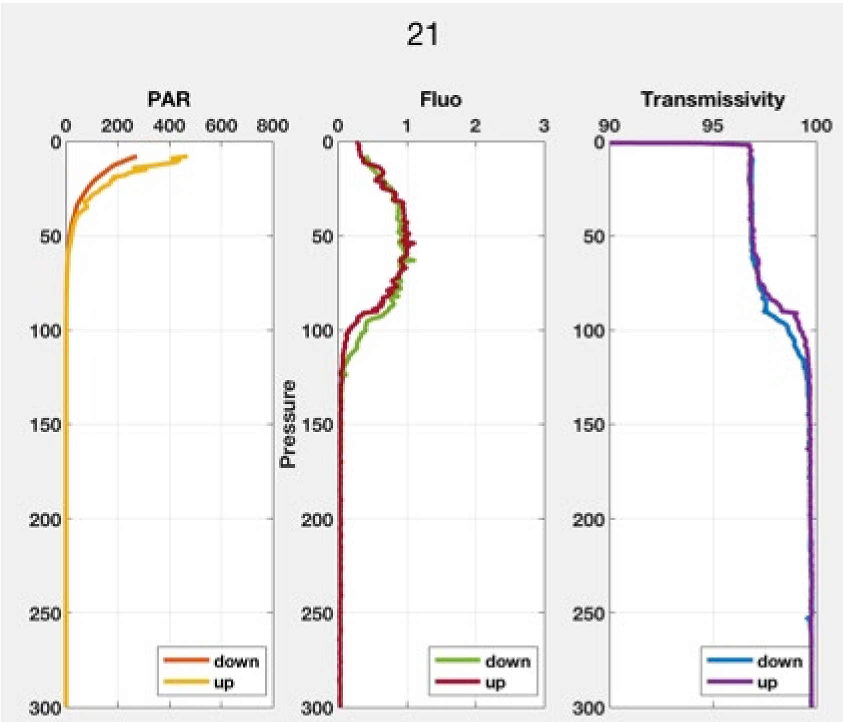


Figure 3: Incident light (PAR), fluorescence (Fluo) and transmissivity for CTD 21 after the storm. Different trace colours distinguish upcasts from downcasts. Note that this was a day cast and that transmissivity does not mirror the decrease in fluorescence towards the surface. Given that this was a mid-day cast, this was likely an NPQ-induced fluorescence maximum.

Voyage Narrative

TABLE OF ACRONYMS

Acronym	Name
TMR	Trace Metal Rosette
TM Fish	Towed intake to supply trace metal clean water
Snow Catcher	Large volume water collector for particle analysis
RESPIRE drifting trap	Drifting particle traps measuring oxygen consumption
ISP	In situ pump for particle collections
Motor head net	Plankton net with forced water supply
CPR	Continuous Plankton Recorder

All times in the Voyage Narrative are local ship time = UTC+11.

Thursday 14 March

The Investigator departed Hobart on schedule at 0800. The morning was spent performing science and MNF party briefing, an emergency muster drill, seagoing induction, toolbox meeting for the afternoon's deck operations, and lab inductions. In Storm Bay a series of equipment tests were undertaken: a mooring anchor dual lift; pneumatic grapple firing; deployment and recovery of the Trace Metal Rosette (TMR); deployment and recovery of the user supplied Snow Catcher – the release mechanism proved to be unreliable and further testing and modification was required; shallow CTD; In situ pump (ISP) deployment; and TM Fish; The Triaxus could not be deployed as there was a communications failure in the tow cable. The cable termination was repaired overnight. Testing was completed by 1900 and we commenced transit to the south along GSM track#2. The CPR was deployed at 2126.

Start Time (local)	Activity
2126	CPR tow

Friday 15 March

Conditions overnight were calm. After a moorings toolbox at 0830 the CPR was recovered (1038) and the TMR deployed just below the surface for cleaning, followed by further testing of the Snow Catcher. This revealed further issues with poor sealing of the vessel. The Triaxus tested with a tow conducted between 1300 and 1440 with all systems functioning correctly. After returning back to the CPR recovery point, it was redeployed at 1538 and our journey south resumed.

Start Time (local)	Activity
1538	CPR tow

Saturday 16 March

The CPR was towed until we reached the SOTS area at 0140. The Triaxus was deployed at 0230 and we commenced a survey of the area consisting of a bow-tie shaped ship track. It failed around 0554 with an intake blockage due to organic material. The TMR was deployed and lowered to 400m at 0813 to clean the equipment. The Triaxus blockage was cleared and a practice deployment and recovery performed before recommencing the survey at 1035. Triaxus communications lost around 1255 and vehicle recovered at around 1340. We continued the survey collecting surface observations only. The Triaxus was redeployed at 1640 and continued surveying through to midnight.

Start Time (local)	Activity
0230	Triaxux tow

Sunday 17 March

CTD #2 was performed at 0035 to 2250m depth and the TMR deployed at 0400 to 1500m depth. The ship was then positioned for deployment of the RESPIRE drifter which commenced around 0730. And completed at 0950. The mid-day bio-optical CTD was deployed at 1211 to a depth of 300m and recovered by 1240. The TM Fish was deployed around 1320, and recovered around 1530. The ISP was deployed at 1600 and recovered at 1940. The Motor net was deployed twice to 90 and 70m at 2020 and three Bongo net deployments to 100m at 2110. A CTD (cast #5) was performed at 0040 to 300m near SOFS-7.5.

Start Time (local)	Activity
0335	CTD to 2250m
0400	TMR to 1500m
0950	RESPIRE drifting trap # 1
1211	CTD to 300m
1320	TM Fish
1600	ISP
2020	Motor head net
2110	Bongo Net to 100m
0040 (Monday 18 March)	CTD to 300m

Monday 18 March

We commenced setting up for SOFS-8 deployment at 0600. The conditions were light with the swell from the SW and winds from the East. There was a ~1.5knot current running from the East. The drogue was deployed at 0600, the surface float was deployed just before 1200. The wire-to-synthetic rope transition occurred at around 1515, and end of the tether was deployed at around 1745. The releases were deployed at around 1830. The mooring was towed around a loop to the target drop site until around 2000 and the anchor was deployed around 2030. Triangulated anchor depth is 4313.4 m at lat: -46.89340 and lon: 142.34494 deg. We moved about a mile from the mooring and did a test dip with the CTD to verify the sensors were functioning. The position of the SOFS-8 mooring was triangulated after the CTD cast, and we continued to collect meteorological observations near SOFS-8 through the night.

SOFS-8 anchor released at 2019-03-18 09:29:22 UTC, -46.892892, 142.337878 with water depth under ship of 4362m. Surveyed position: 46.89340 S, 42.34494 E and anchor depth 4313.4 m.

Tuesday 19 March

Moving a mile away from SOFS-8 a TMR cast to 1500m was performed at 0400 followed by an ISP cast to 300m at 0500. A CTD to 300m depth was performed at noon and completed at 1230, followed by an ISP cast to 1250m. In the evening the SnowCatcher was deployed from the starboard boom. The Zooplankton net was towed from the stern twice. A CTD cast to 300m was performed at 2300.

Start Time (local)	Activity
0400	TMR to 1500m
0530	ISP to 300m
1200	CTD to 300m
1230	ISP to 1250
2000	SnowCatcher
2030	Zooplankton (Bongo) Net tow
2300	CTD to 300m

Wednesday 20 March

Overnight the ship transited to the SAZ-21 site and set up for deployment 9 miles to the North of the anchor drop target. Conditions were light with Easterly winds and waves from the West. A slight current ~0.4-0.6 knots was running to the East. Deck preparation commenced 0600. The top float and first sets of floats deployed at 0800. Final sediment trap deployed at 1120. Anchor released at 1343. Triangulated position: lat -46.82592 lon 141.64815, release depth 4526.2 under ship, anchor depth 4566.0. It took ~12 seconds for the float pack to be submerged. We moved 1 mile away and then conducted a CTD cast to 2250m. Triangulation of the SAZ-21 commenced around 1830. At around 2030 we departed for the RESPIRE drifter.

SAZ-21 anchor released at 2019-03-20 02:45:05 UTC, -46.835878, 141.648389, with water depth under ship of 4600m. Surveyed anchor position: -46.82592 S, 141.64815 E, depth 4566.0 m

Start Time (local)	Activity
1450	CTD to 2250m

Thursday 21 March

A TMR deployment was performed at 0400 to 1500m depth. Recovery of the RESPIRE drifting trap commenced after breakfast at 0730 and was completed by around 1000. We then transited to 10NM North of SAZ-20 to the location of the next drifter deployment. Completed the drifter deployment at 1540. An ISP cast to 1500m commenced at 1630. The Snow Catcher was deployed from the coring boom at 2100. Three Zooplankton net tows were performed from 2130 and then we transited to the SAZ-20 site.

Start Time (local)	Activity
0400	TMR to 1500m
1540	RESPIRE drifting trap # 2
1200	CTD to 300m
1630	ISP to 1500m
2100	SnowCatcher
2130	Zooplankton (Bongo) Net tow

Friday 22 March

The back deck was set up for the SAZ-20 recovery at 0600. The conditions were foggy and calm. The acoustic release was triggered at 0800 and first floats sighted at 0810. The mooring was grappled and secured by 0830. SAZ-20 recovery was completed by 1420. An TMR cast commenced at 1600 to 1500m followed by an ISP cast at 2000 to 1500m. Overnight spent near SOFS-7.5 collecting meteorological observations.

Start Time (local)	Activity
0600	SAZ-20 recovery
1600	TMR to 1500m
2000	ISP to 1500m

Saturday 23 March

Deck set up commenced 0600 for SOFS-7.5 mooring recovery. The remote pickup line was triggered 0820. The recovery line parted around 0930 and a second successful grappling attempt was performed. Buoy on deck 1200. The remainder of the afternoon was spent recovering the lower section of the mooring and was completed at 2100. This was followed by a sequence of TMR, ISP, SnowCatcher and Zooplankton stern tows.

Start Time (local)	Activity
0600	SOFS-7.5 recovery
2030	TMR to 1500m
2230	ISP to 1500m

<u>Sunday 24 March</u>

A TMR cast was performed at 0400. The deck was set up at 0830 for recovery of RESPIRE drifter #2 which was completed by 1130. CTD to 300m deployed at 1224 and completed 1300. Commenced transit South to location of BGC-Argo floats.

Start Time (local)	Activity
0245	SnowCatcher
0400	TMR to 300m
1130	RESPIRE drifting trap # 2 recovered
1224	CTD to 300m

<u>Monday 25 March</u>

CTD cast to 500m at 0600. Continued South towards BGC-Argo float 687. The float was sighted around 1000 and a number of attempts made to capture it by scooping it up in the man overboard recovery device as it passed alongside. The attempts were unsuccessful and we ceased around 1200 with conditions worsening significantly (winds around 35 knots). We then went hove too for the remainder of the day as a large storm moved across north of our location.

Start Time (local)	Activity
0600	CTD to 500m

<u>Tuesday 26 March</u>

After a night hove too with heavy rolling the weather abated sufficiently for us to return to the location of the BGC-Argo float. The float was spotted, but conditions proved too rough for a recovery to be attempted. We commenced transit back North to the SOTS site at 1400.

Wednesday 27 March

We arrived at the site and set up for RESPIRE drifting trap deployment #3. Deployment commenced around 0900. The top float was deployed at 1140, immediately followed by a CTD (#15) to 300m at 1225 which was completed 1254. The ISP was deployed to 1500m around 1300. The TMR was deployed at 1800 to 1300 m. Another ISP cast was performed at 1920 to 1500m depth.

Start Time (local)	Activity
1140	RESPIRE drifting trap # 3 deployed
1225	CTD to 300m
1300	ISP to 1500m
1800	TMR to 1300m
1920	ISP to 1500m

Thursday 28 March

A CTD cast was performed at 0011 to 300m before the ship transited to the test anchor deployment site (46.86S, 142.15E). 0600 the ship was set up 2 miles down weather of the site. Deck set-up commenced 0800 and anchor was deployed at 1132. A CTD was deployed at 1200 to 300m and recovered at 1230. A TM-clean fish was deployed at 1300 to 50m and recovered 1615. We then returned to the test anchor site for triangulation. At 2100 we commenced a zooplankton net tow followed by the Marine Snow Catcher at 2127, the Bongo Net at 2210 and a CTD to 300m at 2310.

Start Time (local)	Activity
0011	CTD to 300m
1200	CTD to 300m
1300	TM-Cleanfish
2100	Zooplankton net tow
2127	Marine SnowCatcher
2210	Bongo Net
2310	CTD to 300m

Friday 29 March

The ship was positioned 1 mile down weather from the test anchor site at 0600. A toolbox was held on the bridge at 0745.The acoustic release was triggered at 0800 and the floats spotted on the surface around 0830 and test anchor floats and instrument recovery completed at 1000. A CTD to 300m was performed at 1200. An ISP cast to 1500m was performed at 1300, followed by the TMR at 1700, ISP at 1900 and CTD to 300m at 2315.

Start Time (local)	Activity
1200	CTD to 300m
1300	ISP to 1500m
1700	TMR to 1500m
1900	ISP to 1500m
2315	CTD to 300m

Saturday 30 March

We stayed in the vicinity of the drifting RESPIRE trap #3 overnight and commenced recovery at 0800 under light and sunny conditions. Recovery was completed by 1020. A CTD to 300m was deployed at 1203 and recovered at 1305. The ship then moved in close to the SOFS-8 buoy and conducted meteorological intercomparisons for the afternoon. The Snow Catcher was deployed at 2023 followed by Zooplankton net tows at 2100 and then ZooRespire at 2123. At 2300 A CTD cast to 300m was performed.

Start Time (local)	Activity
1203	CTD to 300m
2023	Marine SnowCatcher
2100	Zooplankton net tow
2123	ZooRESPIRE
2300	CTD to 300m

Sunday 31 March

The Bongo net was deployed at 0032. Zoo Respire casts were performed up until 0400, followed by a TMR cast to 275m. The ship was then positioned near 46.87S, 142.2E for RESPIRE drifting trap deployment #4 which commenced at 0800 and was completed by 1030. At noon we commenced an ISP cast to 1500m. Zooplankton tow at 2010, and Bongo net tows at 2015.

Start Time (local)	Activity
0032	Bongo net
0400	TMR to 275m
1030	Drifting RESPIRE trap # 4 deployment
1200	ISP to 1500m
2010	Zooplankton tow
2015	Bongo net tow

Monday 1 April

At 0000 we commenced transiting North to the old SOFS-6 site (at 46S) where the bottom portion of the mooring has remained since it failed in November 2017. We set up 2 miles outside the anchor location and waited for sunrise. A toolbox was held on the bridge at 0745 and SOFS-6 recovery commenced after breakfast (0830). The bottom floats were grappled and on-board by 1000 and recovery completed by 1515. An ISP cast was performed at 1600 and a TMR at 2015. A ZooRESPIRE was deployed at 2135 and Bongo nets at 2325 and 0005.

Start Time (local)	Activity
1600	ISP to 1500m
2015	TMR to 1300 m
2135	ZooRESPIRE
2325	Bongo net tow
0005 (Tuesday 2nd April)	Bongo net tow

Tuesday 2 April

0020 We transited back South to the SOTS site and the location of the drifting RESPIRE trap #4. After the toolbox, recovery commenced around 0830 and was completed at 1000. The Triaxus was deployed 1230 and transit to Hobart commenced. The weather deteriorated throughout the afternoon and the Triaxus was recovered around 1800.

Start Time (local)	Activity
1000	Drifting RESPIRE trap # 4 recovered
1230	Triaxus deployed
1800	Triaxus recovered

Wednesday 3 April

We continued our transit under moderate conditions.

Thursday 4 April

We arrived in the river during the night and docked at 0800.

Summary

The voyage was successful. The weather and sea conditions were unusually calm for the first ten days followed by a storm that we diverted south to avoid and consumed our two weather contingency days, followed by moderate conditions for the remainder of the voyage.

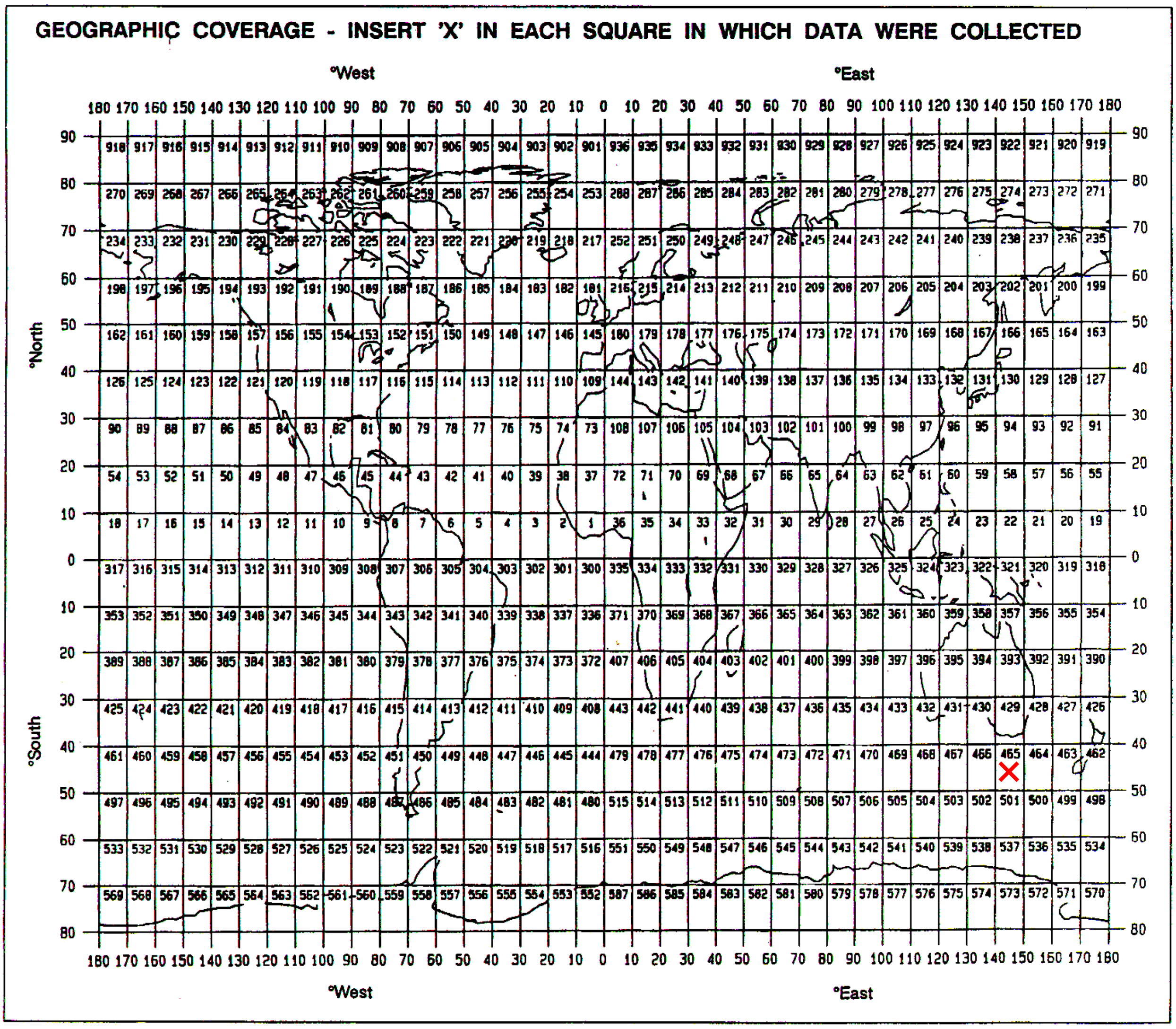
SOTS: The mooring activities continued the sustainment of the multi-disciplinary ocean observatory aimed at understanding the carbon, heat and mass flux contribution of the Sub-Antarctic Zone to the global climate system.

Trace elements: during this voyage ten TMR casts and seven ISP casts were conducted sampling the water column for dissolved and particulate trace elements over 12 and 6 depths respectively to further our understanding of trace element cycling and better identify the controlling mechanisms. In addition the RESPIRE traps were successfully deployed and recovered four times.

Marsden Squares

Move a **red “x”** into squares in which data was collected

× × × × ×



Moorings, bottom mounted gear and drifting systems

Item No	PI See page above	APPROXIMATE POSITION						DATA TYPE enter code(s) from list on last page	DESCRIPTION
		LATITUDE			LONGITUDE				Identify, as appropriate, the nature of the instrumentation the parameters (to be) measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any identifiers given to the site.
		deg	min	N/S	deg	min	E/W		
1	Tom Trull & Eric Schulz	46	53.6	S	142	20.7	E	MO2 M71 M90 H17 D01 D71	Southern Ocean Times Series (SOTS) site: SOFS-8 surface buoy mooring deployed for recovery in April 2020. See diagram in appendix detailing instruments and depths.
2	Tom Trull	46	49.6	S	141	38.9	E	H17 B73 D01	Southern Ocean Times Series (SOTS) site: SAZ-21 sub-surface sediment trap mooring deployed for recovery in April 2020. See diagram in appendix detailing instruments and depths.
3	Tom Trull	46	48	S	141	47,7	E	H17 B73 D01	Southern Ocean Times Series (SOTS) site: SAZ-20 sub-surface sediment trap mooring recovered (deployed in March 2018)
4	Tom Trull & Eric Schulz	47	0	S	142	14	E	MO2 M71 M90 H17 D01 D71	Southern Ocean Times Series (SOTS) site: SOFS-7.5 surface buoy mooring recovered (deployed August 2018). See diagram in appendix detailing instruments and depths.
5	Tom Trull & Eric Schulz	46	0	S	142	8	E	B64	SOFS-6 bottom component recovered (deployed April 2017 and failed November 2017)

Item No	PI See page above	APPROXIMATE POSITION						DATA TYPE enter code(s) from list on last page	DESCRIPTION
		LATITUDE			LONGITUDE				Identify, as appropriate, the nature of the instrumentation the parameters (to be) measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any identifiers given to the site.
		deg	min	N/S	deg	min	E/W		
6	Philip Boyd	46	59	S	142	47	E	B73, B71, H21, H30	RESPIRE Drifting Trap #1 (1 RESPIRE and 1 TM-RESPIRE traps at 150m and 170 m depth) – Deployment 17/03/19, recovery 21/03/19
7	Philip Boyd	46	50	S	142	41	E	B73, B71, H21, H30	RESPIRE Drifting Trap #2 (3 RESPIRE and 2 TM-RESPIRE traps between 150 and 250 m depth) – Deployment 21/03/19, recovery 24/03/19
8	Philip Boyd	47	01	S	142	15	E	B73, B71, H21, H30	RESPIRE Drifting Trap #3 (3 RESPIRE and 3 TM-RESPIRE traps between 150 and 250 m depth) – Deployment 27/03/19, recovery 30/03/19
9	Philip Boyd	47	01	S	142	15	E	B73, B71, H21, H30	RESPIRE Drifting Trap #4 (3 RESPIRE and 2 TM-RESPIRE traps between 150 and 250 m depth) – Deployment 31/03/19, recovery 02/04/19
									Please continue on separate sheet if necessary

Summary of Measurements and samples taken

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
1	Tom Trull	22	Hours	B08	CPR – Continuous Plankton Recorder
2	Bronte Tilbrook	20	days		Continuous pCO2 measurements
3	Tom Trull	21	Hours	H71, H11, H17, H21, H24	Triaxus
4	Robert Strzepek, Pauline Latour	2	Incubations	B01, B02, B07, B08	Size-fractionated (0.2, 2.0, and 20 µm) primary productivity and iron uptake measurements (n = 168) were made on seawater samples collected at 2 stations using the trace metal rosette (TMR) and incubated at six irradiances for 24 h.
5	Robert Strzepek	2	Incubations	B01, B02, B07, B08	Time course experiments were conducted in which size-fractionated (0.2, 2.0, and 20 µm) primary productivity and iron uptake measurements (n = 144) were made on seawater samples collected at 2 stations using the TMR and incubated at two irradiances, in the dark, and in the presence/absence of an herbicide (DCMU).
6	Robert Strzepek	7	TMR	B02, B08	Seawater samples (n = 45) collected by TMR for flow cytometry (preserved with 2% glutaraldehyde), and Fast Repetition Rate fluorometry (FRRF).
7	Robert Strzepek, Pauline Latour	3	TMR	B07, B08, B72	RNA (metatranscriptomic) was collected on Sterivex filters from water samples collected in duplicate from 4 depths at 3 stations using the TMR (n=24), (collected on behalf of U. Tennessee, USA).
8	Robert Strzepek, Pauline Latour	2	TMR	B07, B08, B72	Particles were collected on 0.2 µm and 2.0 µm polycarbonate filters for metaproteomic analyses from water collected at 15 m using the TMR (n=54). Initial ~15 L samples were collected in triplicate from each TMR, and 0.5 – 1.0 L from each treatment of the Fe/Mn addition

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	**DESCRIPTION** **Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.**
					deckboard incubations (see below) (collected on behalf of Dalhousie University, Canada).
9	Pauline Latour, Robert Strzepek	2	Incubation	B01, B02, B07, B08	Primary productivity and iron uptake measurements (n = 72) were made at 2 stations on Fe/Mn addition bioassay experiments. Seawater collected at 15m was used to incubate phytoplankton for 8 days and different treatments were administrated (Fe, Mn, and combinations). Radiolabelled elements (C, Fe) were added 24h before the end of the experiment for uptake measurements. Samples for Fast Repetition Rate fluorometry (FRRF), flow cytometry and trace metal samples (dissolved seawater and filters) were also collected (n = 48, 144, 24 and 24 respectively).
10	M. Ellwood	6	TMR	H30 H32	Filtered (0.2 µm) seawater samples (n=72) collected using trace metal rosette; 1250 m profiles for shore-based analysis of trace element concentrations and stable isotope composition
11	M. Ellwood	10	ISP	H30 H32	Particle samples (n=58) collected onto 0.2 µm Supor filters using McLane pumps in the upper 1250 m for shore-based analysis of trace element concentrations and stable isotope composition
12	M. Ellwood	10	ISP	B71	Particle samples (n=60) collected onto GFF filters using McLane pumps in the upper 1250 m for shore-based analysis of POC/PON
13	M. Ellwood	2	ISP	B07, B08, B72	RNA (metatranscriptomic) was collected on PCTE filters from pump samples (n=6), (collected on behalf of U. Tennessee, USA).
14	M. Bressac	4	Free drifting mooring	B73, H30	Particle samples (n = 30) collected onto 0.2 µm PC filters for shore-based analysis of particulate trace element concentrations and SEM analysis. Particles were collected from free drifting TM-RESPIRE traps.
15	M. Bressac	4	Free drifting mooring	B73, B71	Particle samples (n = 60) collected onto QMA filter membranes for shore-based analysis of carbon and nitrogen concentrations. Particles were collected from free drifting RESPIRE and TM-RESPIRE traps.
16	M. Bressac	4	Free drifting mooring	B73, H30	Filtered (0.2 µm) seawater samples (n=26) collected from RESPIRE and TM-RESPIRE traps for shore based analysis of dissolved trace element concentrations.

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
17	S. Halfter	5	deployments	B09	The Bongo net was used (2 vertical, 3 horizontal tows) to collect zooplankton for species composition analyses (vertical tows) and incubations (horizontal tows).
18	S. Halfter	11	Incubations	B09, B07	Zooplankton was incubated alive (krill, 2 times) and as carcasses (pyrosomes and krill, 5 times) and the O2 decline was measured over 48-60 hours. 3 rows of faecal pellet production incubations were conducted as well (krill, copepods). 1 batch of dead krill was incubated for sampling of bacterial numbers.
19	C. Dithugoe	1	Deployment	B06, B71, H26, B07	The Zooplankton net was used to collect data within the MLD (70 m and 90 m). Two times the sample collected; 25 mm GF Filter (POC & PIC), 0.8 µm PC filters (BSi) and 0.2 µm PC filters (metagenomics and metatranscriptomics). 0.2 µm PC filters folded inside the cyrovial in the -80^{o}C
20	C. Dithugoe	5	Deployments	B06, B71, H26, B07	The Marine Snow Catcher was used to collect data 10 m below the MLD (100 m and 110 m). Three times the sample for suspended particles, slow sinking particles and fast sinking particles; 25 mm GF Filter (POC & PIC), 0.8 µm PC filters (BSi) and 0.2 µm PC filters (metagenomics and metatranscriptomics). 0.2 µm PC filters folded inside the cyrovial in the -80^{o}C
21	Philip Butterworth	17	CTD	B07	Water from the CTD was filtered through Sterivex filters (0.2 µm) for subsequent shore based metagenomic analysis involving high throughput 16S and 18S rRNA gene tag sequencing analysis to elucidate the bacterial, archaeal and micro-eukaryote community structure and composition. 57 samples were collected in total.
22	Philip Butterworth	3	ISP	B07	Material collected on ISP filters (51 µm) was resuspended in 0.2 µm filtered seawater and then filtered through Sterivex filters (0.2 µm) for subsequent shore based metagenomic analysis. Three samples, i.e., three ISP filters, were processed in total. In addition, for each of these three samples, three replicate samples were preserved in glutaraldehyde for subsequent shore based flow cytometry analysis.
23	Philip Butterworth	3	Incubations	B07	Material collected on ISP filters (51 µm) was resuspended in 0.2 µm filtered seawater and then incubated in a series of microrespiration vials (12 vials in total over 3 separate incubations) and the O2 decline was measured over a

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
					period of 72 hours. Following the incubations, material from each vial was divided into two: one half was filtered through a Sterivex filter (0.2 µm) for subsequent metagenomic analysis and the other half was filtered onto a QMA filter (2.2 µm) for subsequent shore based POC analysis.
24	Christina Schallenberg	44	Filters	B02, B71	25 mm GFF filters for high pressure liquid chromatography (HPLC) pigment analysis, kept at -80°C and taken from underway seawater line.
25	Christina Schallenberg	20	Filters	B02, B71	25 mm GFF filters for particulate absorption analysis, kept at -80°C and taken from underway seawater line.
26	Christina Schallenberg	150	Filters	B02, B71	25 mm GFF filters for fluorometric Chlorophyll analysis, kept at -80°C and taken from underway seawater line.
27	Christina Schallenberg	1	Deployment	H16, H17	Continuous ac-9 measurements on the underway line for the duration of the cruise, measuring absorption and attenuation of both filtered and unfiltered seawater
28	Christina Schallenberg	18	Days	H17	Continuous measurements with a Fast Induction and Relaxation (FIRe) instrument on the underway seawater line, assessing photosynthetic competency of phytoplankton
29	Julien Vialat	3	ISP	H32	Particle samples (n=17) collected onto 0.2 µm Supor filters using McLane pumps in the upper 1250 m for shore-based analysis of Pa, Th, and Nd
30	Julien Vialat	3	CTD	H32	Water samples (n = 24) from the CTD was filtered through 0.2 µm filters for subsequent shore based Pa, Nd, and Th analysis
31	Julien Vialat	1	ISP	B71	Particle samples (n=3) collected onto GFF filters using McLane pumps in the upper 1250 m for shore-based analysis of POC/PON
32	Cathryn Wynn-Edwards	63	SAZ sediment trap cups (250ml)	B73	Unfiltered oceanic seawater and particulate matter samples in 250ml cups (n=3*21), collected with three McLane Parflux sediment traps at 1000m, 2000m and 3800m nominal depth for shore-based biochemical analysis.
33	Cathryn Wynn-Edwards	98	Filters	B71	13mm QMA filters (pore size 0.8um) (n=98) for shore-based destructive particulate organic carbon (POC) analysis, taken from CTD Niskin bottles.

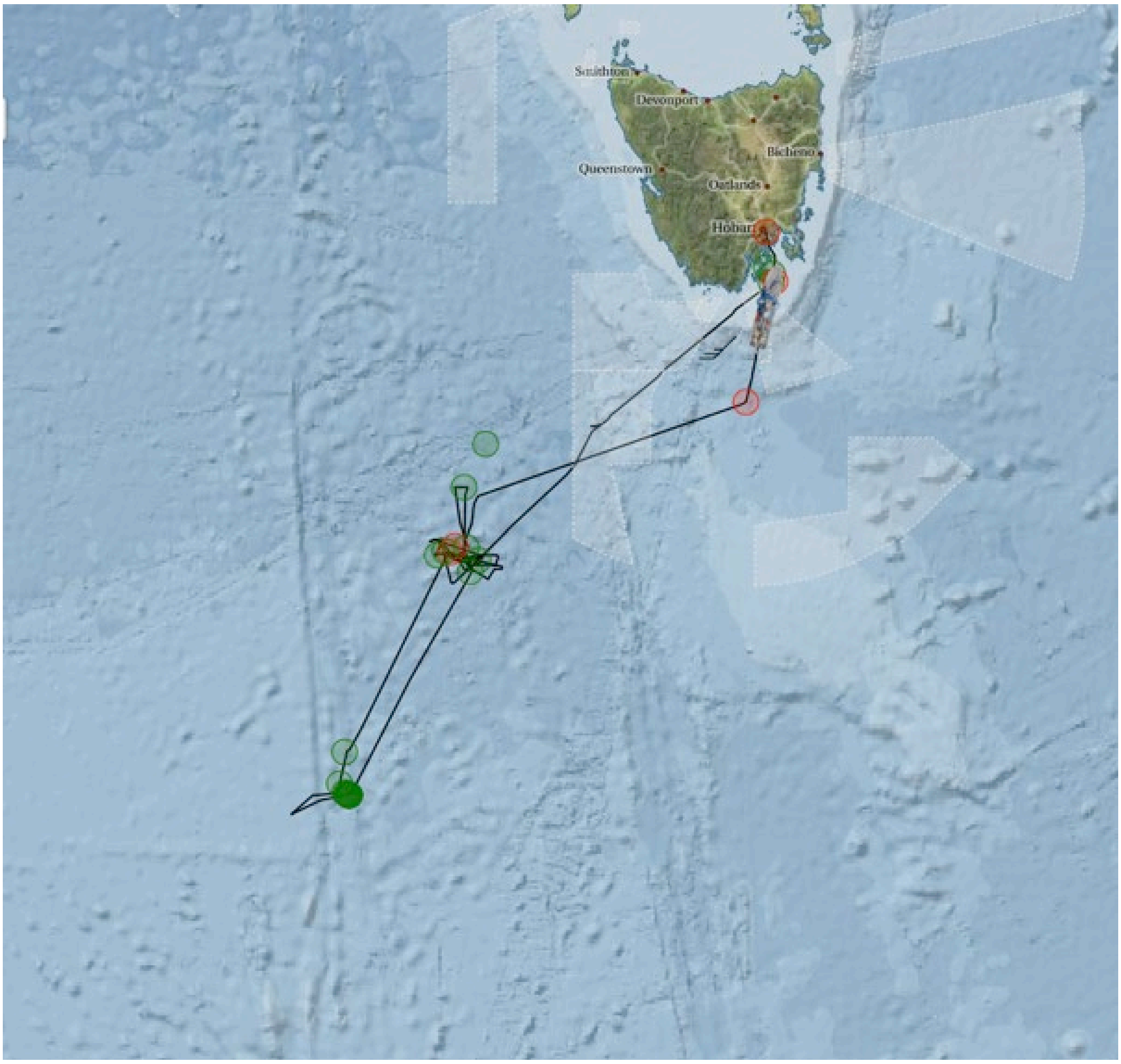
Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
34	Cathryn Wynn-Edwards	16	Filters	B08	13mm filters (pore size 0.8um) for phytoplankton taxonomy identification (coccolithophores) and enumeration, taken from CTD Niskin bottles.
35	Cathryn Wynn-Edwards	14	1L bottles	B08	1L plastic bottles, poisoned with 500ul saturated mercuric Chloride for phytoplankton taxonomy identification and enumeration, taken from CTD Niskin bottles.
36	Di Davies	48	RAS	H74, H27, B08	48 x 500ml Tedlar sample bags of unfiltered open ocean seawater, poisoned with mercuric chloride for shore-based analysis of nutrients, DIC, Alk and phytoplankton taxonomy identification and enumeration.
37	Morgane Perron	28	Filters	M71, H30	28 aerosol filters (Whatman 41 cellulose) were collected along the ship’s track. Samples are stored frozen in the -80C freezer until further analysis (trace metals).
38	Morgane Perron	6	Rain Water	M71, H30	2 rain evets were sampled. Each event results in 3 rain water sample. One 60mL aliquot was filtered (0.2um polycarbonate -PC-) and acidified (120uL HCl), another 60mL aliquot was only acidified 120uL HCl) and the leftover rain water was stored at -4C in the walk-in fridge. Samples will be analysed for trace metals back ashore
39	Morgane Perron	15	Seawater	H30	15 seawater samples were collected during a 7 days aerosol incubation experiment during the voyage. Seawater samples (60mL*3 at incubation time T0 and 125mL*12 at incubation time T7). Samples were filtered (0.2um PC) and acidified to 2uL HCl per mL sample. Seawater will be analysed on shore for trace metal concentration.
30	Morgane Perron	3	Bulk Seawater	H30	3 carboys (2* 10L and 1* 20L) were filled with filtered (0.2um PC) seawater from the TMR and stored in the -4C walk-in fridge for later trace metal analysis and experiments back on shore.
41	Baldry, Kimberlee	52	Stations	B02, B90	Samples were collected from the underway line and analysed using the Chelsea FRRf3. In the day fluorescent light curves (FLC) were performed based on the surface par, and dark FRRf measurements were taken for night-time samples. An intensive 3 day sampling period was undertaken fron the 27-30/3/2019, where measurements were collected every 1-2 hours.

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
42	Baldry, Kimberlee	12	Stations	B02, B90	Surface FRRf (Chelsea FRRf3) measurements were taken from 12 CTD stations (3,7,8,13,15, 17-22) and at the DCM in CTD station 8. In the day a FLC was performed based on the surface par, and dark FRRf measurements were taken for night-time sample.
43	Baldry, Kimberlee	3	Incubations	B02, B90	1-2 hourly FLC measurements taken on the Chelsea FRRf3 in various light/dark adapted states. Measurements were performed using seawater collected from parallel incubation chambers in the first 24 hours of Item No. 1 (Incubation 1 High-light, Incubation 2 high-light and Incubation 2 2nd Highest light
44	Elizabeth Shadwick	15	Discrete samples from CTD casts	H74, H27	12 samples for each DIC and Alk on 2 deep CTD casts, 6 samples for each DIC and Alk for each of 13 shallow CTD casts. Samples will be analysed for DIC (coulometry) and Alk (potentiometric titration) at CSIRO in Hobart.

Curation Report

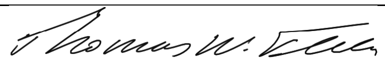
Item #	DESCRIPTION
1.	SOTS Project: Water and particle samples collected from the CTD and underway system (detailed in the SOTS Metadata Report below) are returned to CSIRO Marine and Atmospheric Research for chemical analyses and then discarded following quarantine protocols.
2.	SOTS Project: Moored sediment trap samples recovered from the SAZ-18 mooring are processed at the ACE CRC. 7/10 of each sample is consumed by analyses for particulate organic carbon, particulate inorganic carbon, and biogenic silica. These results are provided for public use via the IMOS Ocean Data Portal. 2/10 are made available for biological studies by various groups via agreement with SOTS Chief Scientist Tom Trull. 1/10 is archived at the ACE CRC.

Track Chart



Acknowledgements

We are grateful to the MNF and ASP for ship access prior to the mobilization day, and for excellent support at sea. We thank the directors of the MNF, IMOS, and the ACE CRC (for support of SOTS.

Your name	Tom Trull
Title	Chief Scientist
Signature	
Date:	4/4/2019

List of additional figures and documents

Appendix A CSR/ROSCOP Parameter Codes

Appendix B Mooring diagrams

Appendix C Triangulation results

Appendix D Summary of mooring debrief discussions

Appendix A - CSR/ROSCOP Parameter Codes

	METEOROLOGY
M01	Upper air observations
M02	Incident radiation
M05	Occasional standard measurements
M06	Routine standard measurements
M71	Atmospheric chemistry
M90	Other meteorological measurements

	PHYSICAL OCEANOGRAPHY

	MARINE BIOLOGY/FISHERIES
B01	Primary productivity
B02	Phytoplankton pigments (eg chlorophyll, fluorescence)
B71	Particulate organic matter (inc POC, PON)
B06	Dissolved organic matter (inc DOC)
B72	Biochemical measurements (eg lipids, amino acids)
B73	Sediment traps
B08	Phytoplankton
B09	Zooplankton

H71	Surface measurements underway (T,S)
H13	Bathythermograph
H09	Water bottle stations
H10	CTD stations
H11	Subsurface measurements underway (T,S)
H72	Thermistor chain
H16	Transparency (eg transmissometer)
H17	Optics (eg underwater light levels)
H73	Geochemical tracers (eg freons)
D01	Current meters
D71	Current profiler (eg ADCP)
D03	Currents measured from ship drift
D04	GEK
D05	Surface drifters/drifting buoys
D06	Neutrally buoyant floats
D09	Sea level (incl. Bottom pressure & inverted echosounder)
D72	Instrumented wave measurements
D90	Other physical oceanographic measurements

	CHEMICAL OCEANOGRAPHY
H21	Oxygen
H74	Carbon dioxide
H33	Other dissolved gases
H22	Phosphate
H23	Total - P

B03	Seston
B10	Neuston
B11	Nekton
B13	Eggs & larvae
B07	Pelagic bacteria/micro-organisms
B16	Benthic bacteria/micro-organisms
B17	Phytobenthos
B18	Zoobenthos
B25	Birds
B26	Mammals & reptiles
B14	Pelagic fish
B19	Demersal fish
B20	Molluscs
B21	Crustaceans
B28	Acoustic reflection on marine organisms
B37	Taggings
B64	Gear research
B65	Exploratory fishing
B90	Other biological/fisheries measurements

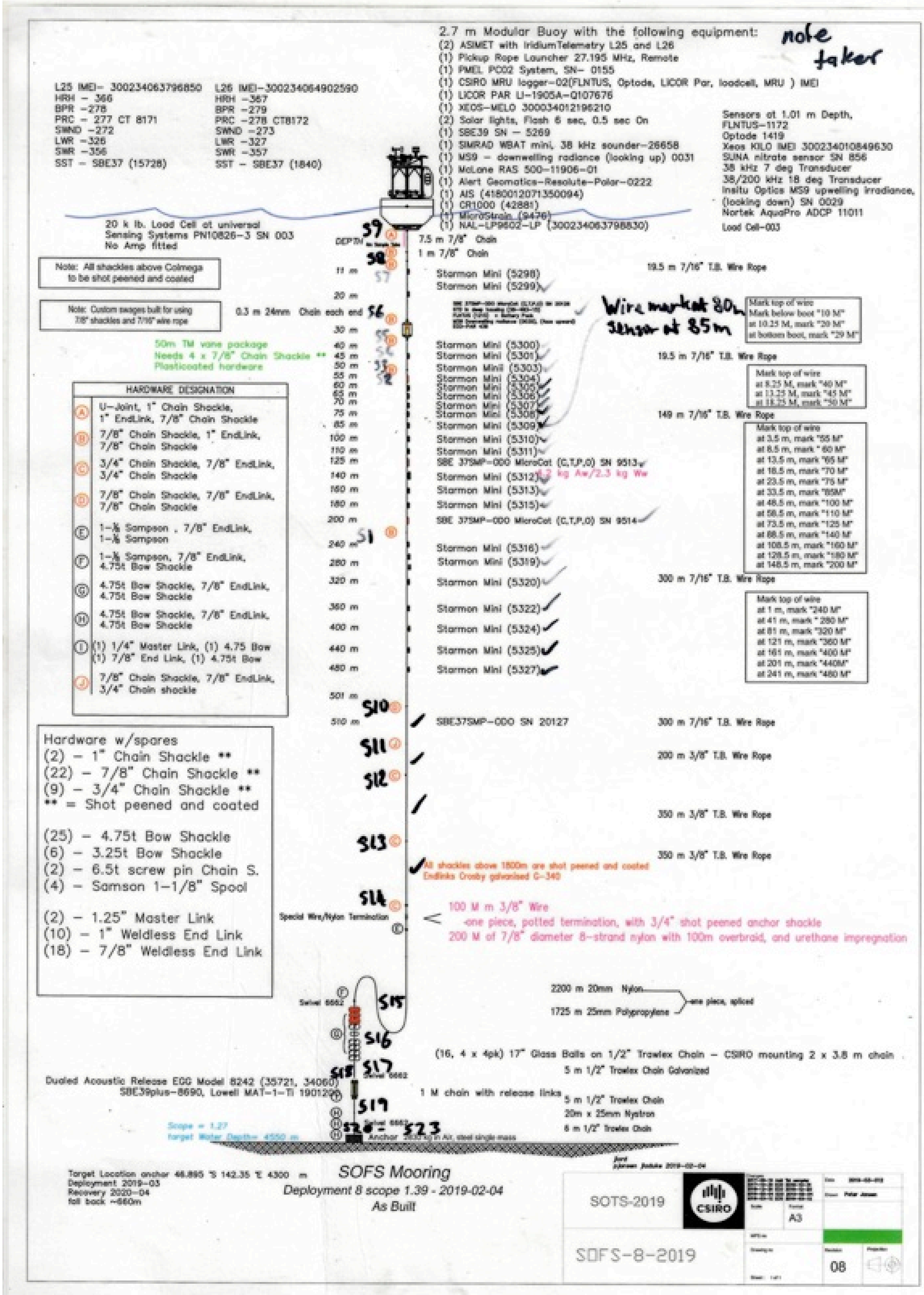
	MARINE GEOLOGY/GEOPHYSICS
G01	Dredge
G02	Grab
G03	Core - rock
G04	Core - soft bottom

H24	Nitrate
H25	Nitrite
H75	Total - N
H76	Ammonia
H26	Silicate
H27	Alkalinity
H28	PH
H30	Trace elements
H31	Radioactivity
H32	Isotopes
H90	Other chemical oceanographic measurements

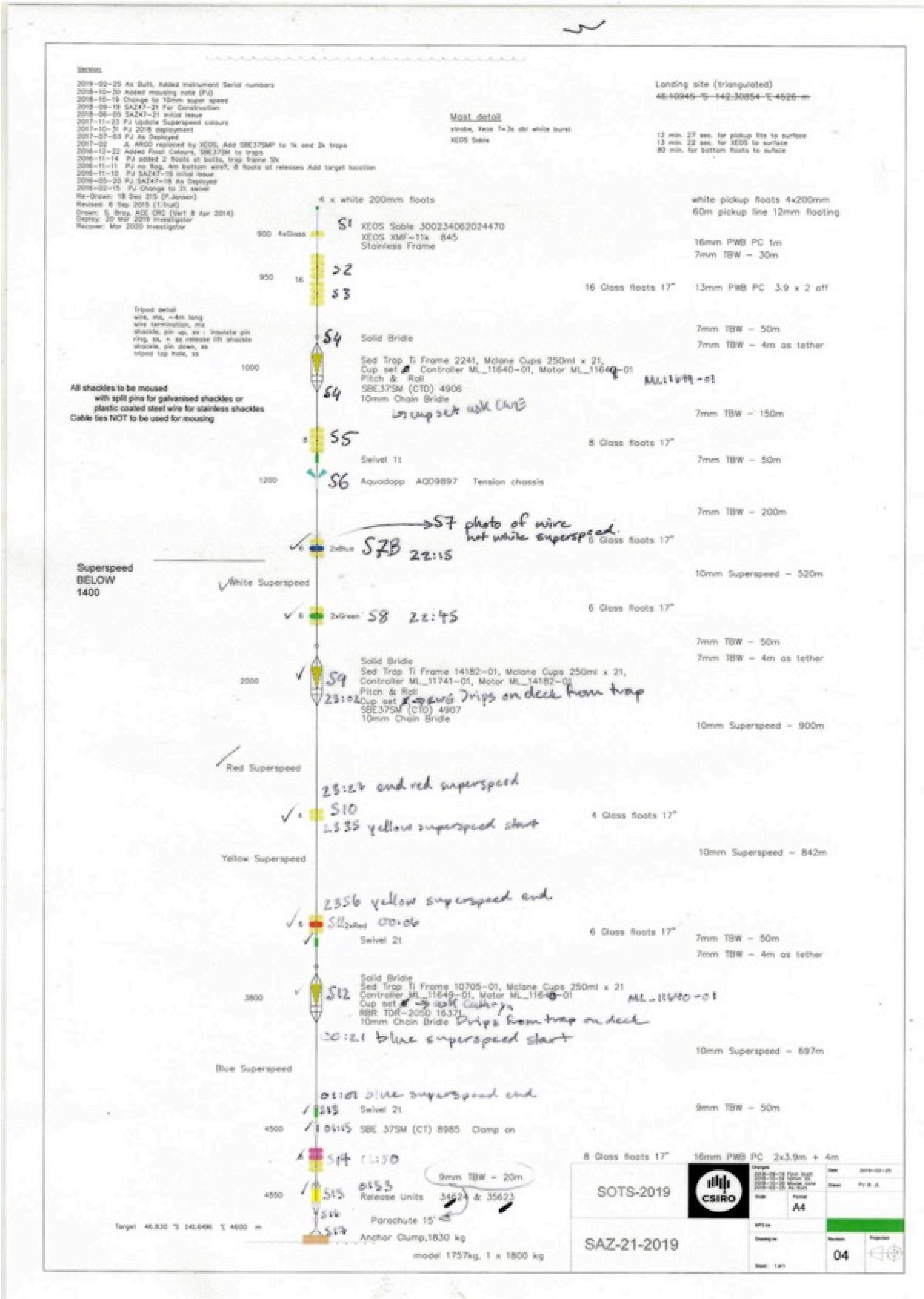
G08	Bottom photography
G71	In-situ seafloor measurement/sampling
G72	Geophysical measurements made at depth
G73	Single-beam echosounding
G74	Multi-beam echosounding
G24	Long/short range side scan sonar
G75	Single channel seismic reflection
G76	Multichannel seismic reflection
G26	Seismic refraction
G27	Gravity measurements
G28	Magnetic measurements
G90	Other geological/geophysical measurements

	MARINE CONTAMINANTS/POLLUTION
P01	Suspended matter
P02	Trace metals
P03	Petroleum residues
P04	Chlorinated hydrocarbons
P05	Other dissolved substances
P12	Bottom deposits
P13	Contaminants in organisms
P90	Other contaminant measurements

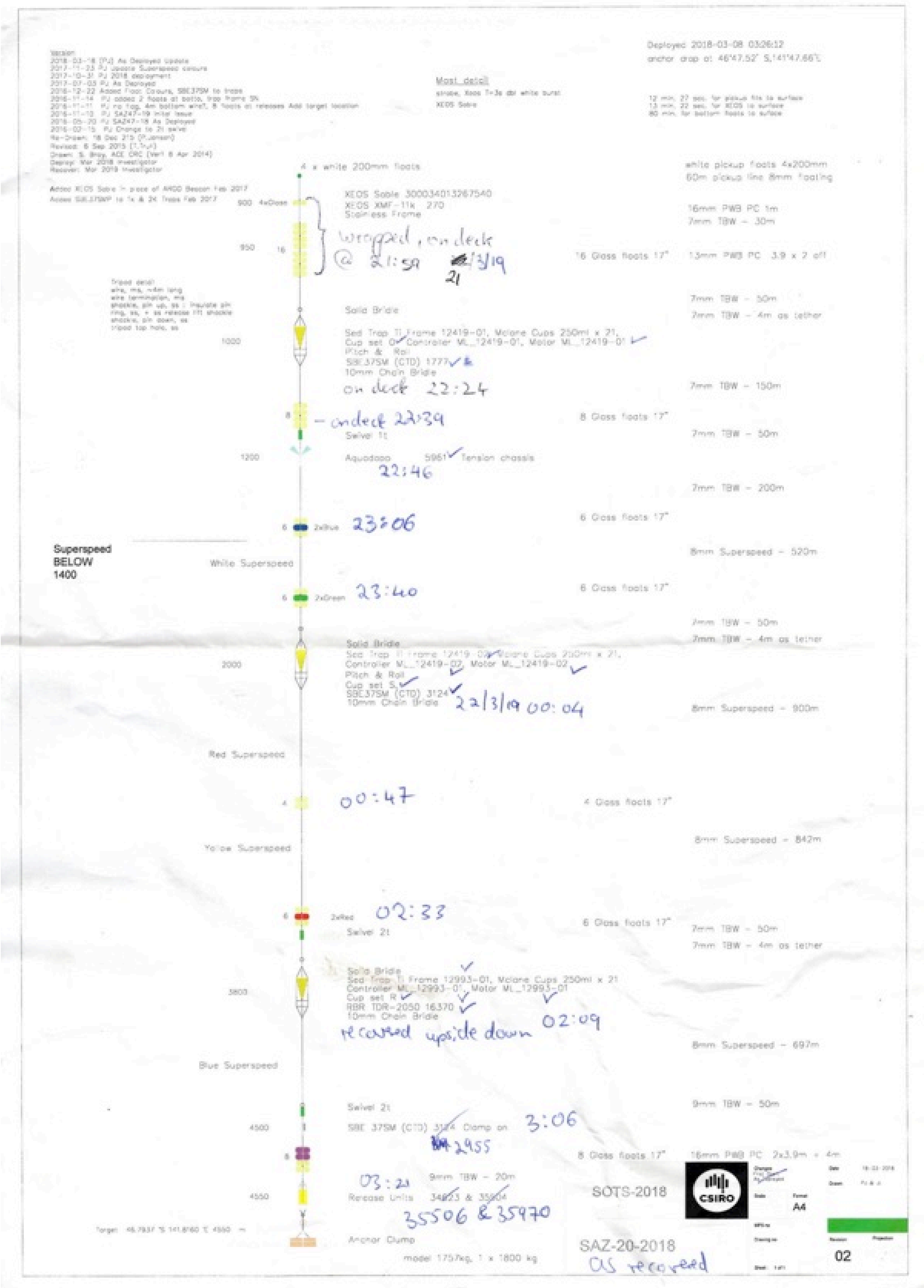
Appendix B Mooring diagrams



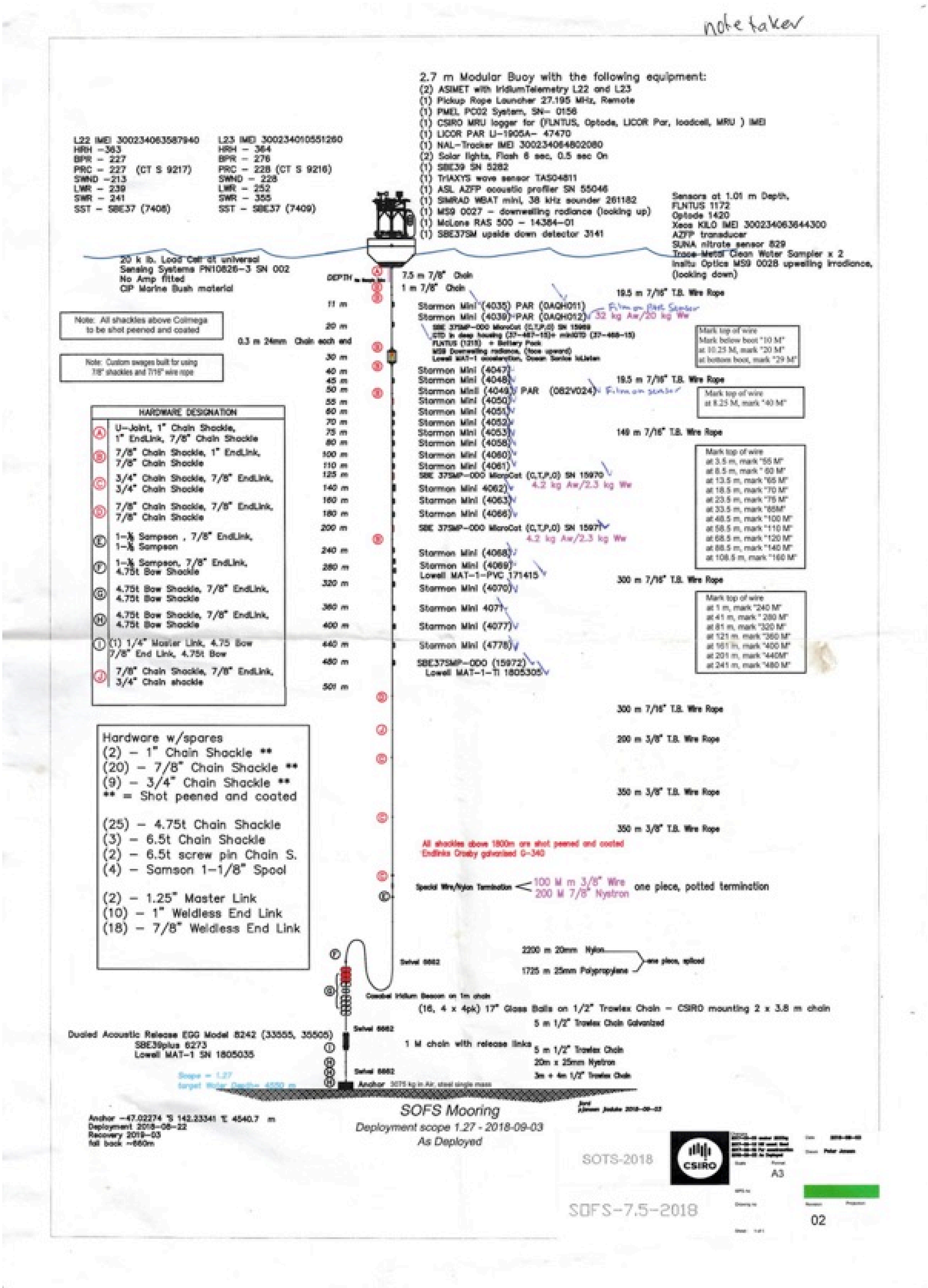
SOFS-8 As deployed



SAZ-21 As deployed

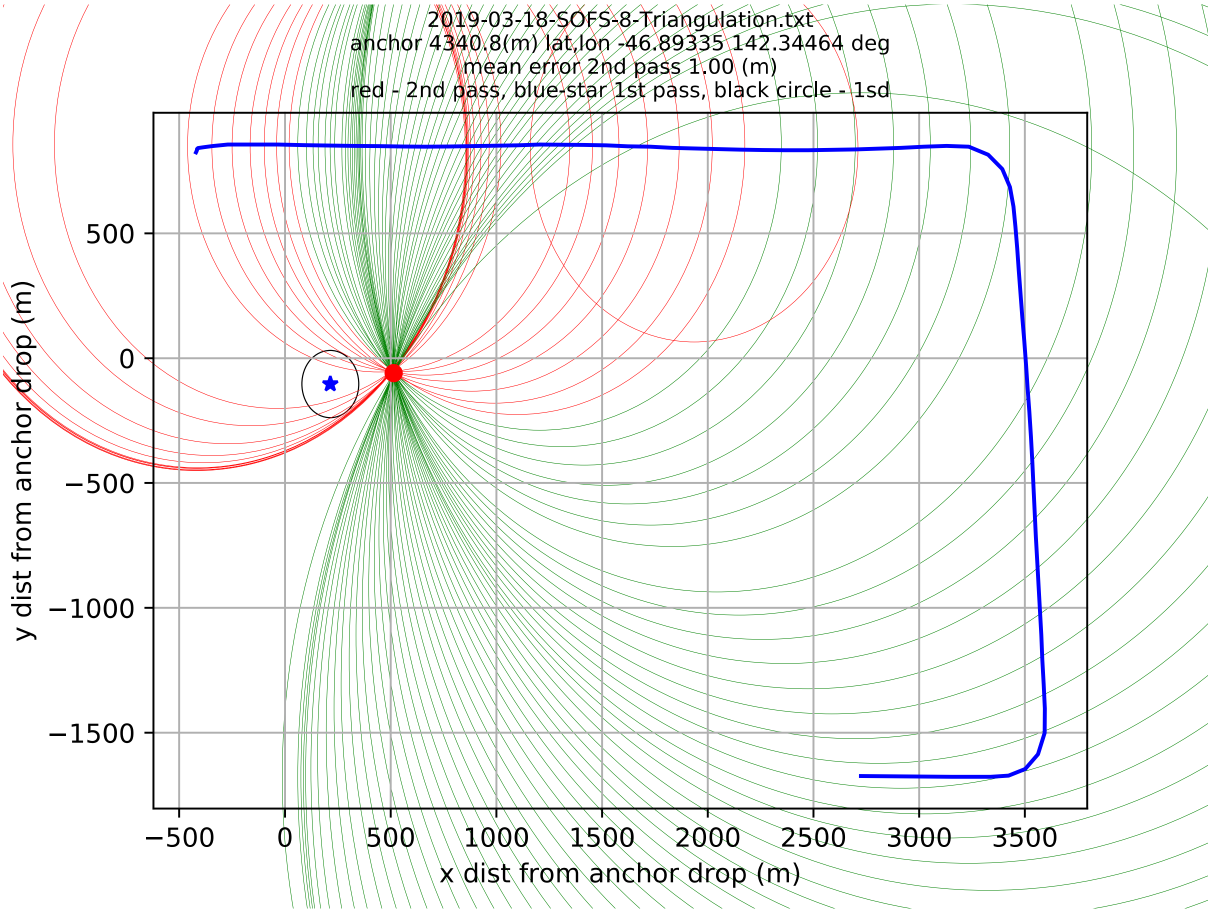


SAZ-20 As recovered

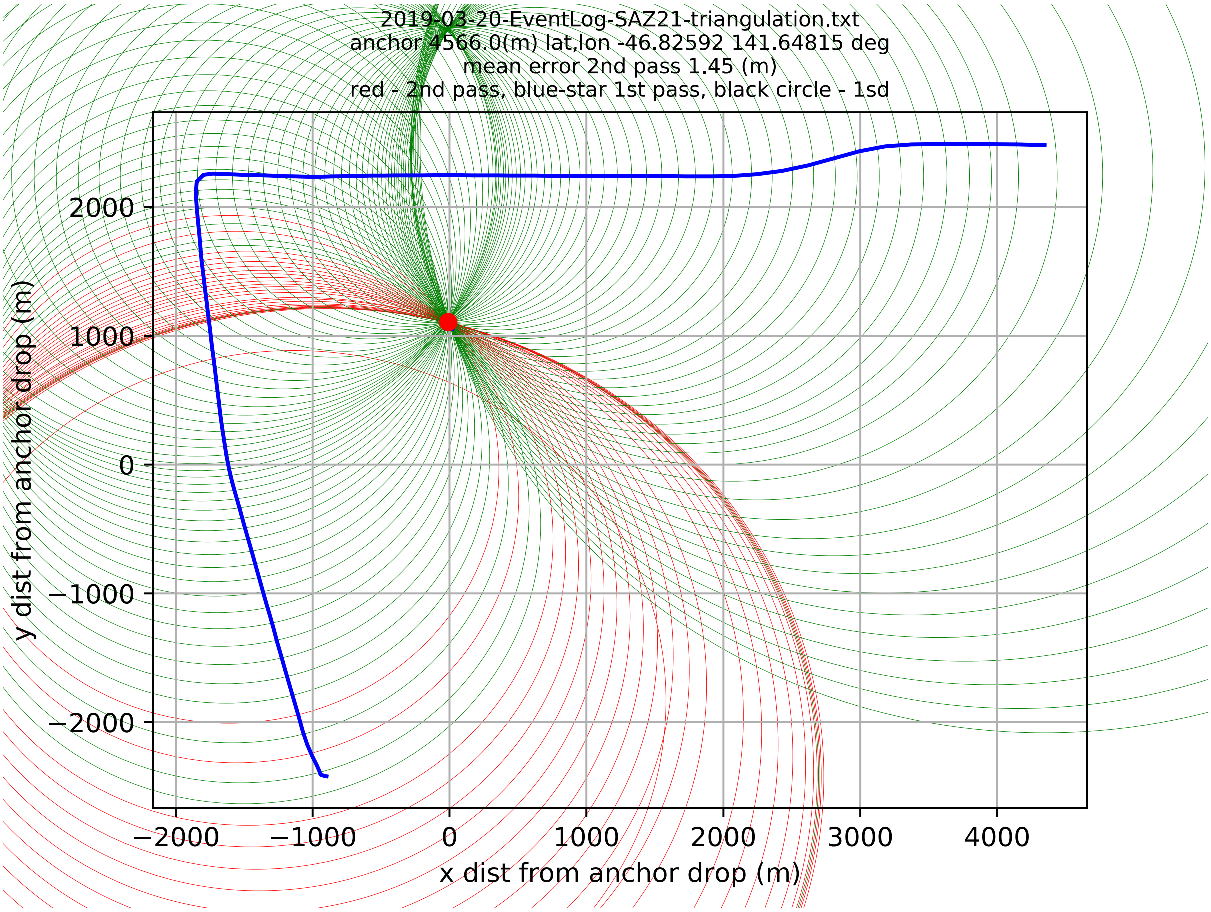


SOFS-7.5 As recovered

Appendix C Triangulation results



SOFS-8 Trangulation results



SAZ-21 Trangulation results.