Cruise Report

International Thwaites Glacier Collaboration

RV/IB Nathaniel B Palmer

NBP19-02

RV/IB *Nathaniel B. Palmer* north of the Thwaites Eastern Ice Shelf
Photo: A. Mazur

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CRUISE REPORT

RV/IB Nathaniel B. Palmer

Cruise NBP19-02

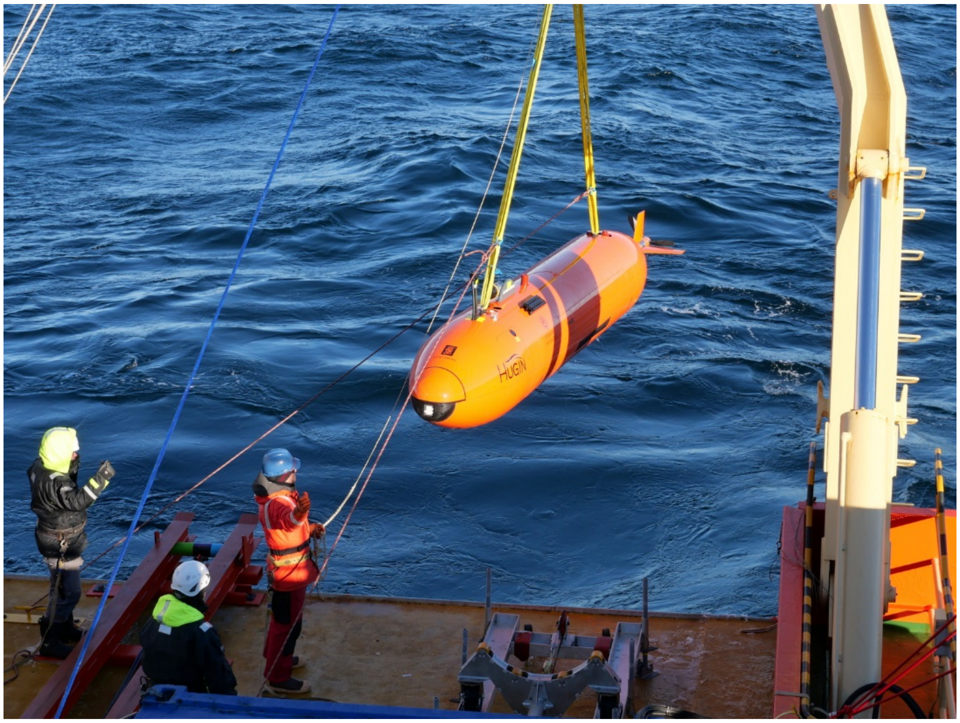
January-March 2019

First research cruise of the International Thwaites Glacier Collaboration

Physical oceanography
Marine geology and geophysics
Coastal geology and geomorphology

Amundsen Sea

R.D. Larter, B.Y. Queste, L. Boehme, S. Braddock, A.K. Wåhlin,
A.G.C. Graham, K.A. Hogan, R. Totten Minzoni, M. Barham,
G. Bortolotto de'Oliveira, R. Clark, V. Fitzgerald, S. Karam, J.D. Kirkham, A. Mazur,
P. Sheehan, M. Spoth, P. Stedt,L. Welzenbach, Y. Zheng, J. Andersson, J. Rolandsson,
C. Beeler, J. Goodell, E. Rush and T. Snow



Frontispiece. Upper photo: launching the Hugin AUV near the Lindsey Islands on February 13th. Lower photo: extracting a full jumbo gravity core liner from the core barrel near Thwaites Eastern Ice Shelf on March 10th.

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Summary

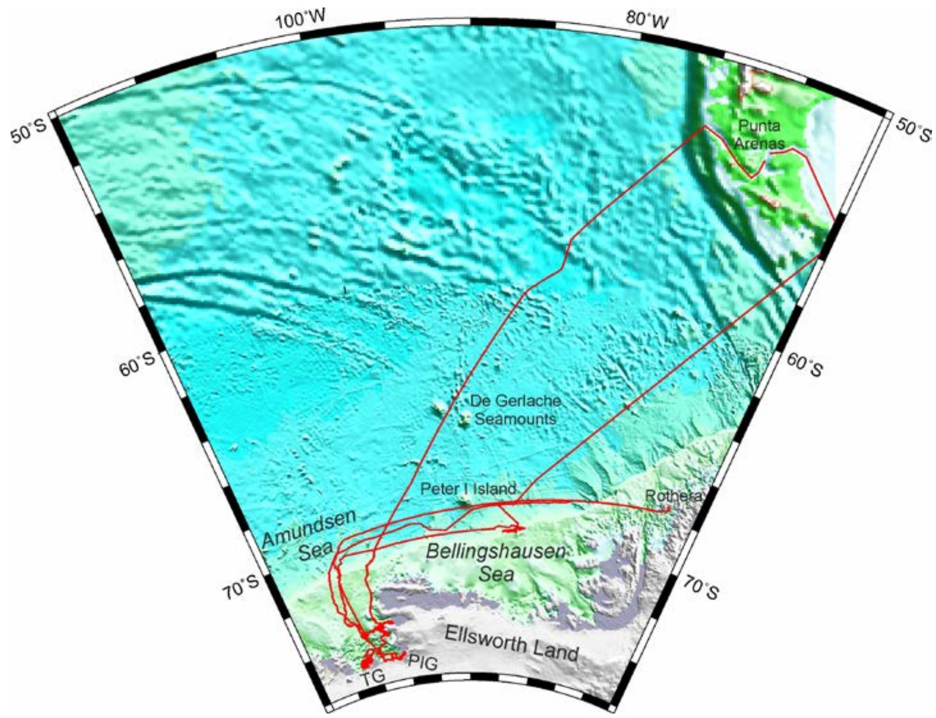
Cruise NBP19-02 involved the first phase of work for three different projects that are components of the International Thwaites Glacier Collaboration (ITGC), which is a five-year initiative jointly funded by the US National Science Foundation (NSF) and UK Natural Environment Research Council (NERC). In broad terms the activities were physical oceanography (TARSAN[1] project), marine geology and geophysics (THOR[2] project) and terrestrial geology and geomorphology (GHC[3] project). The cruise was also tasked to recover, download data from and redeploy a number of long-term oceanographic moorings.

Overall, 34 days were allocated for science activities within a 52 day cruise, the remainder being required for transit, except for a small amount of contingency time. A mechanical issue at the start of the cruise and a medical evacuation resulted in a total loss of more than 12 days. A three-day extension to the cruise was granted to partially compensate for this lost time, but significant impact on the science program was unavoidable. Nevertheless, members of the different project teams worked together very effectively in a spirit of collaboration and interleaved activities to make the best possible use of the time available.

The retreat of the Thwaites Glacier Tongue over the past few years and the break-up of fast ice in front of the glacier earlier this season allowed us work in an extensive area that had never previously been accessible to research ships. Despite the time lost, substantial datasets and sample sets were collected that will provide a good basis for initial work on all three projects. The objectives relating to the moorings were only partially achieved, as some moorings remained covered by densely-packed sea ice throughout the season and we were unable to find any evidence of another. Overall though, there were some significant achievements. The cruise has enabled a good start to the three research projects, fostered collaborations between the different teams, and achieved excellent outreach for ITGC through the activities of the journalists and science writers participating.

1. TARSAN – Thwaites-Amundsen Regional Survey and Network Integrating Atmosphere-Ice-Ocean Processes
2. THOR – Thwaites Offshore Research
3. GHC – Geological History Constraints of the Magnitude of Grounding-Line Retreat in the Thwaites Glacier System

A



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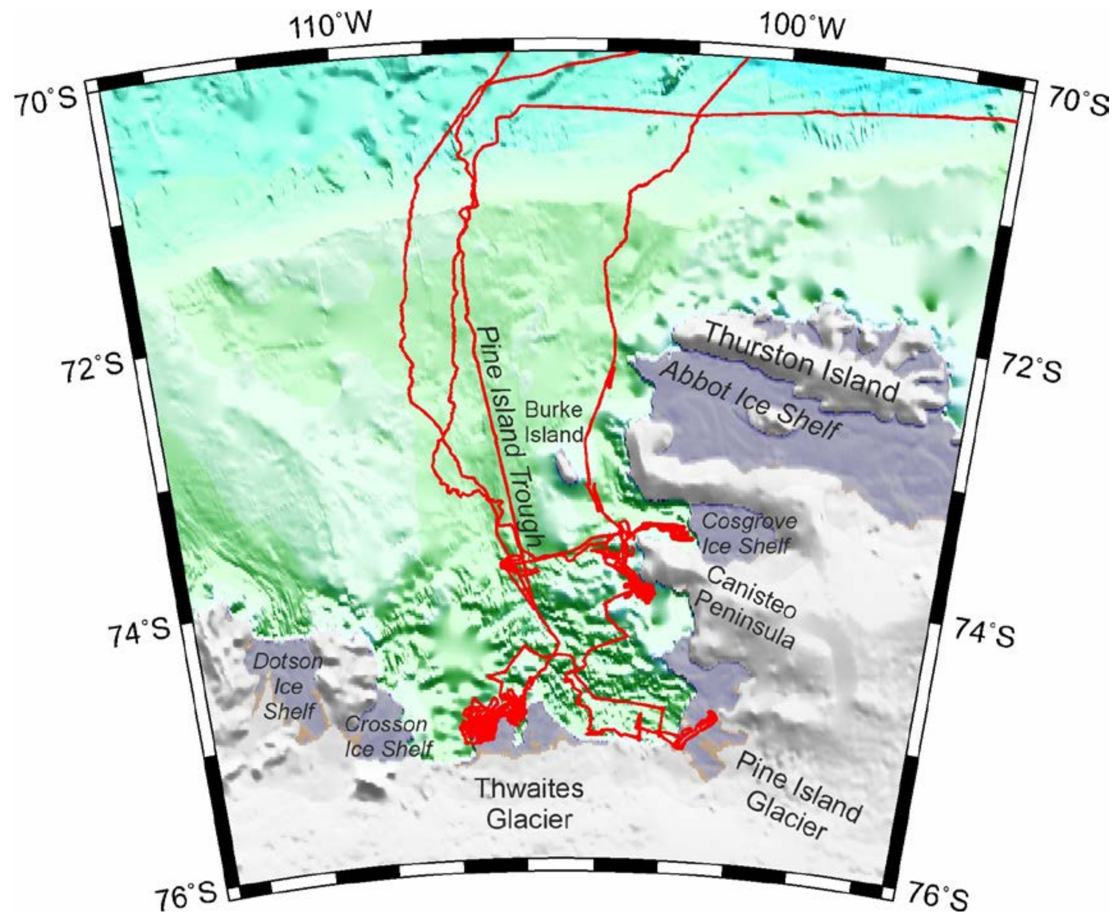

Figure 1A. Track of RV/IB *Nathaniel B. Palmer* during cruise NBP19-02 (red) overlaid on shaded relief display of bathymetry (from International Bathymetric Chart of the Southern Ocean (IBCSO) in region south of 60°S, from Smith & Sandwell (1997) further north). TG – Thwaites Glacier, PIG – Pine Island Glacier. **B.** Track of RV/IB *Nathaniel B. Palmer* during cruise NBP19-02 (red) in Amundsen Sea overlaid on shaded relief display of IBCSO bathymetry. A larger scale track chart is included as a fold out at the back of this report.

Acknowledgements

Planning and preparation for this inaugural cruise of the International Thwaites Glacier Collaboration on the RV/IB *Nathaniel B. Palmer* involved contributions from many program managers, administrators, operations and logistics staff and scientists in both the US and UK. We are indebted to them and to the U.S. National Science Foundation-Office of Polar Programs and the U.K. Natural Environment Research Council for supporting this research.

A total shipboard complement of 58 people were involved in the cruise over nearly two months. We appreciate the dedication of all shipboard personnel, as well as the support of family and friends ashore. We especially thank Captain Brandon Bell and Chief Mate Rick Wiemken who indulged us in our ambition to get very close to Thwaites Glacier and demonstrated their skill in maneuvering the vessel to make possible recovery the Hugin AUV and gliders in sometimes challenging circumstances. We are also grateful to all of the ECO personnel who contributed to the smooth running of the cruise. ASC staff provided invaluable help in preparing and mobilizing for the cruise, and the quality of technical support we received at sea was excellent throughout. We are especially grateful to Cindy Dean for stepping up to take on the MPC role in mid-February, while also continuing to cover he normal MLT duties.

Access to up-to-date satellite imagery showing the distribution of sea ice is invaluable when planning activities in the Amundsen Sea. In this respect we are grateful to Paul Wachter and Benjamin Kowala of the German Aerospace Center (DLR) who provided TerraSAR-X images, Andreas Cziferszky and Andrew Fleming at BAS who provided Sentinel-1 images from Polarview, and the staff of the U.S. National Ice Center.

Shipboard Participants

Scientific and Media (26)

R.D. Larter	BAS	Chief Scientist and THOR project lead
B.Y. Queste	UEA	TARSAN project lead
S. Braddock	Univ. Maine	GHC project lead
L. Boehme	Univ. St Andrews	TARSAN project seal tagging lead
A.K. Wåhlin	Univ. Gothenburg	TARSAN project AUV lead
A.G.C.Graham	Univ. Exeter	THOR project marine geophysicist
K.A. Hogan	BAS	THOR project marine geophysicist
R. Totten Minzoni	Univ. Alabama	THOR project marine geologist
A. Mazur	Univ. Gothenburg	TARSAN project oceanographer
P. Sheehan	UEA	TARSAN project oceanographer
M. Barham	BAS	Oceanographer (moorings)
L. Welzenbach	Rice Univ.	THOR project outreach
G. Bortolotto d'Oliveira	Univ. St Andrews	Graduate student (oceanographer)
R. Clark	Univ. Houston	Graduate student (marine geologist)
V. Fitzgerald	Univ. Alabama	Graduate student (marine geologist)
S. Karam	Univ. Gothenburg	Graduate student (oceanography)
J.D. Kirkham	BAS	Graduate student (marine geophysicist)
M. Spoth	Univ. Maine	Quaternary geologist
P. Stedt	Univ. Gothenburg	Graduate student (oceanographer)
Y. Zheng	UEA	Graduate student (oceanographer)
J. Andersson	MMT	AUV engineer
J. Rolandsson	MMT	AUV engineer
T. Snow	NSIDC	Media liaison and ITGC SCO rep.
C. Beeler	Public Radio Int'l	Journalist
J. Goodell	Rolling Stone Magazine	Journalist
E. Rush	NSF/National Geographic	Writer

BAS = British Antarctic Survey; UEA = University of East Anglia; MMT = Marine Map Tech; NDIDC= National Snow and Ice Data Center; NSF = National Science Foundation; SCO = Science Coordinating Office.

Antarctic Support Contract (11)

L. Loughry	ASC	MPC (until February 19th)
C. Dean	ASC	MLT (and MPC from February 19th)
G. Aukon	ASC	ET
B. Bjork	ASC	ET
J. Greenberg	ASC	MT
C. Greto	ASC	MT (until February 19th)
M. Lewis	ASC	MT (from February 19th)
J. Mowatt	ASC	MT
J. Patterson	ASC	MT
C. Linden	ASC	Multibeam
A. Clair	ASC	IT

Ship's Company (21)

B. Bell	Captain	L. Andrada	AB Seaman
R. Wiemken	Chief Mate	J. Delacruz	AB Seaman
R. Potter	2nd Mate	F. Naraga	AB Seaman
L. Zeller	3rd Mate	M. Sales	AB Seaman
T. Rafferty	Chief Engineer	S. Villanueva	AB Seaman
S. Buker	1st Engineer	J. Isaacs	AB Cook
G. Taylor	2nd Engineer	E. Gemezon	AB Cook
K. Naylon	3rd Engineer	J. Gilmore	AB Cook
R. Labatos	Oiler	A. Toledo	AB Cook
D. Plaza	Oiler		
R. Rogando	Oiler		
R. Tamayo	Oiler		

Figure 2. NBP19-02 shipboard scientific party and ASC staff.
From left to right: Y. Zheng, B.Y. Queste, A. Clair, C. Dean, L. Boehme, M. Lewis, F. Stedt, J. Rolandsson, G. Bortolotto d' Oliveira, A. Mazur, J. Mowatt, S. Karam, L. Welzenbach, J. Greenberg (at back), A.K. Wåhlin, T. Snow, R.D. Larter, A.G.C. Graham, J.D. Kirkham, J. Goodell, P. Sheehan, R. Clark, R. Totten Minzoni, V. Fitzgerald, E. Rush, S. Braddock, M. Spoth, M. Barham, J. Patterson, J. Andersson, K.A. Hogan, C. Beeler.

1. Introduction

NBP19-02 was the first research cruise of the International Thwaites Glacier Collaboration (ITGC), a five-year initiative jointly funded by the US National Science Foundation (NSF) and UK Natural Environment Research Council (NERC) which is part of UK Research and Innovation (UKRI). The overall aims of the ITGC are to improve knowledge of the processes responsible for the accelerating ice mass loss from the Thwaites Glacier and to use this knowledge as a basis for better predictions of how much and how fast the glacier will contribute to future sea-level rise.

The ITGC consists of eight individual science projects and a Science Coordinating Office (SCO). The projects range from ones that are mainly focused on improving numerical ice sheet models, through ones that will investigate processes operating at the base and the margins of the glacier, to ones that will study the grounding zone and processes beneath the ice shelves and ones that will study the longer-term history of the glacier and how it interacts with the adjacent ocean on various timescales.

This cruise involved teams from three ITGC projects:

- Thwaites-Amundsen Regional Survey and Network Integrating Atmosphere-Ice-Ocean Processes (TARSAN)
- Thwaites Offshore Research (THOR)
- Geological History Constraints of the Magnitude of Grounding-Line Retreat in the Thwaites Glacier System (GHC)

Additionally, the cruise was tasked to recover, download data from and redeploy a number of long-term oceanographic moorings.

The TARSAN project had the largest time allocation (18 days). The main TARSAN objectives on the cruise were to conduct the first missions with an autonomous underwater vehicle near Thwaites Glacier, to place satellite tags on a number of Elephant and Weddell seals that will record and transmit oceanographic data, to recover ocean gliders deployed during the preceding cruise, and to use CTD casts and an ocean glider to investigate oceanographic processes.

The THOR project had a time allocation of 10 days to conduct detailed bathymetry and sub-bottom profiler surveys of the seabed and to collect sediment cores from the area close to the front of Thwaites Glacier. A broad range of analyses will be conducted on the sediment cores to extract records of ocean forcing before the start of the instrumental record, the retreat of the glacier from the inner continental shelf, and the timing and frequency of subglacial water discharges from upstream of the grounding line.

The GHC component of the cruise, to which two days were allocated, involved study of raised beaches on groups of islands in the eastern part of Pine Island Bay in order to determine records of relative sea-level change and thus constrain the long-term rate of glacial isostatic adjustment in the region.

Four days were allocated for recovery and redeployment of moorings. Allowance for the time required for transit to and from the southern Amundsen Sea and a small amount of contingency time resulted in a total time of 52 days being allocated to the cruise.

A problem with the ship's rudder, which emerged on January 28th while moving to Cabo Negro to take on fuel, resulted in final departure from Punta Arenas being delayed until the afternoon of January 31st, which completely used up the contingency time before the cruise had started.
The *Palmer* reached the Amundsen Sea continental shelf on February 9th and initial activities were centered on the island groups near the tip of Canisteo Peninsula, which were the focus of GHC work and where the TARSAN team aimed to tag seals. After this initial phase of work we headed towards Thwaites Glacier itself, recovering and redeploying a mid-shelf oceanographic mooring on the way. Before the *Palmer* reached the glacier, however, a medical emergency forced us to turn around on the morning of February 15th and head to the British Antarctic Survey Rothera research station on the Antarctic Peninsula.

The transit to Rothera took four days, even though four engines were used to run at 13 kts whenever conditions allowed. We had to wait there for the return flight of the BAS Dash-7 aircraft that took the patient to Punta Arenas, as it would bring a replacement marine technician. The return flight was cancelled due to high winds in Punta Arenas the day after the *Palmer* arrived at Rothera, so in the end we remained there for more than two days. After the transit back to the Amundsen Sea we restarted work on February 25th, so in all the medical

evacuation resulted in the loss of 10 days from the science program. One of the ocean glider recoveries that was an objective of the TARSAN project was achieved during the return transit from Rothera.

After discussion with NSF the cruise was extended by three days to compensate for some of the time lost. A longer extension would have caused severe difficulties for some members of the scientific party who had other professional and personal commitments after the cruise. Moreover, a longer extension would have been unlikely to have enabled much additional work since formation of new sea ice in the Amundsen Sea usually accelerates rapidly after mid March.

An intensive program of work in front of Thwaites Glacier, followed by a few days activity near Pine Island Glacier, a brief work period near the eastern side of Thwaites, and finally a return visit to the area near Canisteo Peninsula, were packed into the time between February 26th and March 12th. On the morning of March 13th, however, observing that satellite data showed that our exit route from the Amundsen Sea, a narrow corridor between areas of 8–10 tenths ice coverage on the middle shelf, was closing rapidly, and our progress overnight having been blocked by older ice drifting down on us from the north, we decided it was time to head north.

During the remaining science time some further oceanographic data were collected along transects across the shelf break and upper slope in the Amundsen and Bellingshausen seas, and additional bathymetric survey data were also collected. Unfortunately the remaining ocean glider that we had intended to recover had stopped transmitting positions, and despite searching over a broad area it was not found.

Only two moorings out of a possible five were recovered and redeployed. Some equipment on one of the recovered moorings was lost after an encounter with the ship's propeller. Three moorings remained under densely packed sea ice on the outer shelf throughout the season, and we were unable to find any evidence of one of the two near Pine Island Glacier.

The time lost due to the rudder problem at the start of the cruise and to the medical evacuation inevitably impacted the time remaining for science. By the end of the cruise the cumulative time taken working on TARSAN project objectives was approximately 13 days (out of an

allocation of 18 days) and the time taken working on THOR objectives was approximately 7 days (out of an allocation of 10 days). The GHC team were able to go ashore on four different days (not counting one on which they were recalled soon after landing due to worsening weather), which is a good return for an allocation of 2 days of ship time.

Despite the time lost due to unforeseen events the cruise was successful in achieving a range of scientific objectives, including:

Achievements:

- First autonomous underwater vehicle missions near Thwaites Glacier, including two on which the vehicle ventured beneath the ice front.
- Two ocean glider missions, one of 5 days duration, close to the front of Thwaites Glacier and CTD transects across and along troughs leading under the ice front.
- Satellite tags placed on 11 seals, including two on seals that were found on ice floes close to the front of the Eastern Ice Shelf.
- First multibeam bathymetry and sub-bottom acoustic profiler surveys over extensive areas in front of Thwaites Glacier.
- First sediment cores collected closer to Thwaites Glacier than the northern tip of the Eastern Ice Shelf
- Multibeam bathymetry survey conducted over a 10 km-wide corridor of sea-floor in front of Pine Island Glacier that had been exposed as a result of calving line retreat since 2017.
- A new transect of closely-spaced CTD casts conducted along the front of Pine Island Glacier.
- Surveys conducted on and samples collected from three island groups that will enable relative sea-level records to be reconstructed.
- Two long-term moorings recovered and redeployed.
- Extensive outreach through the activities of the journalists and science writers participating on the cruise.

2. Timetable of Events

January 2019

28 Embarkation of the scientific party. RV/IB *Nathaniel B Palmer* departed from Muelle Prat in the evening and transited to Cabo Negro to take bunkers.

29 Bunkering completed, but transited overnight to Muelle Mardones to allow investigation of rudder problem.

30 Divers investigate rudder problem.

31 Divers continue work and rudder function fully restored. RV/IB *Nathaniel B Palmer* departed from Muelle Mardones at 15:50 local time (18:50 UTC) heading towards western end of Strait of Magellan.

February

1 Trial deployment of Hugin AUV ‘Ran’ in western part of Strait of Magellan, north of Isla Desolación.

2-7 Transit to Amundsen Sea. Recorded multibeam echo sounder, sub-bottom profiler and ADCP data along most of transit once out of Chilean territorial waters.

8 Deep-water CTD to full ocean depth near foot of continental slope. Encountered dense band of sea ice across continental slope and shelf edge.

9 Emerged from sea ice into polynya in early hours of morning. CTD, kasten corer and megacorer deployed near Demas ice Tongue of Abbot Ice Shelf.

10 CTD, Hugin AUV and glider deployed near southern tip of Burke Island. Hugin recovered to remedy a problem and redeployed. Started transit to Edwards Islands, but turned back to recover Hugin after distress call received. Arrived at Edwards Islands and field parties (Quaternary geology and seal tagging) went ashore using zodiac boats. Multibeam bathymetry survey conducted along fast ice edge between Edwards and Brownson islands.

11 Hugin AUV deployed for buoyancy test near Edwards Islands, then transit to Schaefer Islands. Field parties went ashore but were soon recalled due to deteriorating weather. Multibeam bathymetry survey conducted in Ferrero Bay in conditions unsuitable for any other activity.

12 Returned to Schaefer Islands and field parties went ashore in zodiacs.

13 Hugin AUV deployed or Doppler velocity log test near Schaefer Islands. Glider recovered northwest of Schaefer Islands. Returned to near islands and deployed Hugin AUV on mission into outer part of Ferrero Bay. Field parties went ashore on eastern of the two Lindsey Islands. One zodiac boat was damaged during recovery.

14 Difficult Hugin AUV recovery in marginal conditions after second zodiac was punctured during first attempt. Transit to mid-shelf mooring, stopping for two CTD casts on the way. Mooring recovered and CTD cast conducted at mooring site.

15 Multibeam bathymetry survey conducted in mid-trough area while preparing to re-deploy mooring. Mooring re-deployed and position triangulated. Began transit south towards Thwaites Glacier, but decision made to carry out medical evacuation and the ship turned to head toward the British Antarctic Survey's Rothera station at 13:52 UTC.

16-18 Transit to Rothera station, southern Antarctic Peninsula at 13 kts, where conditions allowed.

19 Arrived at Rothera station. Patient taken ashore by RHIB from the station and flown out on Dash-7 to Punta Arenas. Test deployment of megacorer in Ryder Bay.

20 Return Dash-7 flight from Punta Arenas, on which replacement marine technician was due to travel, cancelled due to high winds. Boating activities at Rothera also cancelled for the day. Hugin AUV deployed for tests in Ryder Bay following maintenance work.

21 CTD cast in Ryder Bay conducted in response to request from station. Scientist from station collected water and RHIB from station ran repeatedly between temporary wharf in South Cove and the ship to enable exchange visits. Dash-7 arrived from Punta Arenas carrying replacement marine technician landed. Technician was brought to ship by RHIB from station, and ship departed to head back to Amundsen Sea.

22-24 Transit to Amundsen Sea at 13 kts, where conditions allowed. Glider deployed on NBP19-01 recovered on 23rd near 70° S, 93° W.

25 Complete transit to Amundsen Sea. CTD cast in deep basin in outer Pine Island Bay.

26 Three CTD casts on way to tip of Thwaites Glacier Eastern Ice Shelf. Multibeam bathymetry and sub-bottom profiler survey along ice front heading south then west. UEA glider deployed ~10 miles from ice front.

27 CTD, kasten corer, megacorer (twice) and jumbo gravity corer deployed at site near tip of remnant glacier tongue. Multibeam bathymetry and sub-bottom profiler survey in embayment west of remnant glacier tongue. CTD at site where glider deployed on previous day.

28 Two cNODE beacons deployed in preparation for Hugin AUV mission in SE part of embayment west of remnant glacier tongue, but Hugin deployment deferred due to weather. Three CTD casts on way to core site near where glider deployed on 26th. Kasten corer, megacorer and jumbo gravity corer deployed at this site. Transited to SE part of embayment and deployed Hugin AUV.

March

1 Two CTD casts conducted for Hugin calibration. Transect of five CTD casts perpendicular to ice margin. Hugin AUV recovered, followed by another calibration CTD. cNODE recovered. Caltech glider deployed. Jumbo gravity corer and megacorer deployed at site in SE part of embayment.

2 Caltech glider recovered after reporting problems. Multibeam bathymetry survey conducted to fill remaining gaps in coverage embayment west of remnant glacier tongue. Two CTD casts conducted along main SW-NE trough. Transect of five CTD casts across trough close to latitude of tip of remnant glacier tongue. Multibeam bathymetry survey north of tongue.

3 Transited to southern end of main SW-NE trough and conducted transect of 4 CTD casts. UEA glider recovered. CTD, kasten corer and megacorer deployed at site north of remnant glacier tongue. Multibeam bathymetry survey conducted to north of core site, then on transit to embayment between remnant glacier tongue and eastern Ice Shelf.

4 Five CTD casts conducted in embayment between remnant glacier tongue and eastern Ice Shelf. Multibeam bathymetry survey extended in embayment. UEA glider deployed. Transited to area north of Eastern Ice Shelf to tag seals. Seal tagging team reached ice floes using zodiac boat.

5 Transited back to embayment between remnant glacier tongue and eastern Ice Shelf, deployed 4 cNODE beacons and then Hugin AUV. Four CTD casts conducted for Hugin calibration. Recovered UEA glider. Three kasten corers, megacorer and jumbo gravity corer deployed at three closely-spaced sites.

6 Hugin AUV recovered. Jumbo gravity corer and megacorer (twice) deployed at site near southernmost point in embayment between remnant glacier tongue and eastern Ice Shelf. cNODES recovered. Mutibeam survey extended to north of embayment. Transit to inner Pine Island Bay started.

7 Six CTD casts conducted on transit to inner Pine Island Bay. Northern Pine Island mooring recovered. CTD cast conducted near southern Pine Island mooring site, but no evidence of mooring itself found.

8 Transect of 14 CTD casts conducted along front of Pine Island Glacier. Multibeam survey conducted over 10 km-wide strip of sea floor exposed by calving line retreat since early 2017.

9 Mooring deployed at southern Pine Island site and position triangulated. CTD cast conducted near mooring site for calibration. Transited west to repeat CTD previous transect across coastal current, stopping at intervals to make acoustic transmissions in search of previous southern Pine Island mooring. Transect of 6 CTD casts conducted across coastal current.

10 CTD, kasten corer and jumbo gravity corer deployed at site near where eastern side of Eastern Ice Shelf meets grounded ice. Jumbo gravity corer and megacorer deployed at site further from ice margin. Four CTD casts conducted along edge of sea ice to northeast of Eastern Ice Shelf.

11 Transit to eastern side of Pine Island Trough. Transects of CTD cast conducted parallel to and perpendicular to Pine Island Trough on approach to Edwards Islands. Field parties (Quaternary geology and seal tagging) went ashore on islands using zodiac boats. Two CTD casts conducted in deep basin to NW of islands while field parties were ashore.

12 Multibeam bathymetry survey conducted in Cranton Bay, then 5 CTD casts, kasten corer and box corer deployed in surveyed area. Two more CTD casts conducted on transit towards Ferrero Bay.

13 Encountered ice during multiple attempts to find route to Fererro Bay. Started transit north toward outer shelf.

14 Transit northwards continued. Transect of 8 CTD casts across shelf edge and slope started.

15 Transect of CTD casts across shelf edge and slope completed. Transit towards Bellingshausen Sea.

16 CTD cast at same location as first one of the cruise. Transit towards Bellingshausen Sea.

17 Transit to Bellingshausen Sea. Search for second Caltech ocean glider.

18 Search for glider continued. Transect of 8 CTD casts across Bellingshausen Sea shelf edge and upper slope.

19 Transect of CTD casts across shelf edge and slope completed. Multibeam bathymetry survey over lower part of Belgica Fan. Started transit to Punta Arenas.

20-24 Transit to Punta Arenas. The *Palmer* tied up at Muelle Prat at 17:00 local time on March 24th.

3. Narrative

3.1 Beginnings - transit to the Amundsen Sea and starting work

After leaving Muelle Prat in Punta Arenas on the evening of January 28th, the *Palmer* took bunkers at Cabo Negro. On the way to Cabo Negro, a mechanical problem emerged that resulted in a further day and a half of delay before our final departure from Punta Arenas at 15:50 local time on January 31st. Before exiting the western end of the Strait of Magellan, we paused to deploy the University of Gothenburg Hugin AUV ‘Ran’ for a trial mission, which went well. Over the following three days, we encountered increasingly rough seas on the transit southwest towards the Amundsen Sea, but subsequently conditions improved rapidly. The first sightings of icebergs occurred on February 6th before reaching 65° S. We conducted a deep-water CTD cast at the foot of the continental slope on February 8th, just as we encountered a band of sea ice obstructing our route onto the shelf. The ice slowed our progress significantly, but early in the morning on February 9th we emerged into a polynya on the eastern Amundsen Sea continental shelf.

We conducted a CTD cast and trial deployments of the kasten corer and megacorer near the western front of the Abbot Ice Shelf before proceeding southwards between the King Peninsula and Burke Island. We paused near the southern tip of Burke Island to deploy an ocean glider on a mission designed to measure the water fluxes through the gateway between Burke Island and the Lindsey Islands. We reached the Edwards Islands (73° 52’ S, 103° 00’ W) on February 10th and field parties from the TARSAN and GHC projects made their first small boat landings.

3.2 First phase of work - small islands and a mooring recovery

During the first week in the Amundsen Sea we have made good progress towards several cruise objectives. Field parties from the GHC and TARSAN projects visited three different island groups in the Pine Island Bay area (Edwards, Schaefer and Lindsey islands). The GHC team, assisted in the field by some of the THOR team, surveyed and sampled raised beaches on each island group to allow reconstruction of the history of relative sea level change in the region. This will provide long-term glacial isostatic uplift rates, which are an important input to numerical ice sheet models and an essential correction to satellite gravity measurements used to determine contemporary ice mass change. The TARSAN team succeeded in attaching

satellite tags to one elephant seal and three Weddell seals, and within days the tags were already providing valuable oceanographic and behavioral data via ARGOS satellites. Tags would have been placed on a greater number of seals but most animals were still at too early a stage in their annual moult cycle, so any tags would have been lost in a matter of days.

The TARSAN group from the University of Gothenburg conducted a range of Hugin AUV trial deployments during the field teams' rest periods between island landings. On February 13th the Hugin was sent on its first longer mission, spanning the time that field parties were ashore on the Lindsey Islands. This was a 13-hour investigation of the water properties and very high-resolution sea floor morphology along a profile near the mouth of Ferrero Bay. Earlier the same morning, the TARSAN glider, which had been deployed near the southern tip of Burke Island on February 10th, was recovered near the Lindsey Islands, having collected detailed oceanographic data across the 'gateway' between these islands. In the remaining time between landings the THOR team directed multibeam bathymetry surveys of previously uncharted areas to study the clues the seabed morphology reveals about processes that occurred at the ice bed at times in the past when grounded ice covered the continental shelf. A more extensive survey of the previously uncharted southern half of Ferrero Bay, up to the front of the Cosgrove Ice Shelf, was conducted on February 11th–12th after field parties had to be recalled from the Schaefer Islands due to rapidly deteriorating weather conditions.

After the last of the initial island landings on February 14th, the *Palmer* transited to the site of a long-term oceanographic mooring in the middle of Pine Island Trough, the main shelf trough extending northward from Pine Island and Thwaites glaciers. Three CTD casts were conducted along this transit, including one at the mooring site. The mooring had been deployed 5 years ago from RRS *James Clark Ross* on the NERC iStar Program cruise, JR294. Despite being in place for such a long time, the mooring released on receiving an acoustic command and was recovered successfully. Many of the instruments on the mooring had recorded continuously over the 5-year deployment period, so these data will be an enormously valuable resource for understanding the incursion of Circumpolar Deep Water towards Pine Island and Thwaites glaciers. A new mooring was deployed at the same location a few hours later.

Departing from the mooring site our next intended destination was the front of Thwaites Glacier itself. As the transit southward began, however, it became clear that a person on board was in need of a level of medical care not available on the ship. In consultation with NSF, and

based on medical advice from UTMB, the decision was made to proceed as swiftly as possible to the British Antarctic Survey (BAS) research station at Rothera, from where the patient could be flown to Punta Arenas. The *Palmer* turned to head towards Rothera at 14:00 UTC on February 15th.

3.3 Interlude at Rothera

The transit to Rothera took four days steaming at 13 kts, when conditions allowed. The wharf at Rothera is presently being rebuilt, so when the *Palmer* arrived there on the morning of February 19th the patient was taken ashore by boat and then flown to Punta Arenas on the BAS Dash-7 aircraft. A marine technician also departed at the same time for personal reasons and a replacement was already in Punta Arenas waiting for the return flight to Rothera, which was intended to take place the following day. Unfortunately, local easterly winds at Rothera gusting up to 30 kts and even more severe conditions in Punta Arenas early on February 20th resulted in cancellation of the return flight that day. The *Palmer* remained in Ryder Bay for a further day until the Dash-7 bringing the replacement technician arrived in the afternoon of February 21st. Once the technician was on board, the *Palmer* started the transit back to the southern Amundsen Sea. NSF gave dispensation to proceed at 13 kts when conditions allowed so as to return to the Thwaites Glacier region as soon as possible.

Tests of the megacorer and the Hugin AUV were conducted in Ryder Bay while the *Palmer* was waiting off Rothera. A brand new megacorer had been used at the only site cored on the cruise up to this point and all but one of the tubes had failed to close. Adjustments had since been made and these proved to be successful, with all but one tubes closing and recovering >40 cm of sediment during the test in Ryder Bay on February 19th. The Hugin AUV had needed some maintenance work following the last recovery in difficult conditions near the Lindsey Islands early on February 14th, so a test deployment was needed to check its performance before it could be sent on its next mission. A short test deployment was carried out early in the afternoon on February 20th after the windy conditions that had prompted cancellation of the Dash-7 flight that day had subsided. The test was successful, confirming that the AUV was ready for a full-length mission. A request was received from the station at Rothera for the ship to conduct a CTD cast and collect water samples from specified depths in Ryder Bay. This was done early on February 21st, and a student working with the Dutch program at Rothera came to the ship to collect the water samples. Exchange visits also took

place that day with a few people from the station coming to see the ship while a larger number from the Palmer went ashore for a couple of hours and were given guided tours of some of the station facilities.

One of the TARSAN project objectives on the cruise is to recover two ocean gliders in the Bellingshausen Sea that were deployed on the previous Palmer cruise. In consultation with the PI of the previous cruise, the decision was taken to try to recover one of these on the transit back to the Thwaites region and to leave the other to be recovered on the final transit back to Punta Arenas. The glider was recovered very efficiently about 120 miles northeast of Thurston Island in relatively calm conditions on February 23rd.

3.4 At Thwaites Glacier

The *Palmer* arrived back in Pine Island Bay in the evening of February 25th, ten days after the scientific program had been interrupted. During the following week we collected multibeam bathymetry survey over more than 1500 km^2 of seabed that was previously unsurveyed, conducted 28 full water depth CTD casts, collected sediment cores from 4 sites, deployed an ocean glider that collected dive data independently for 5 days, and sent the Hugin AUV on a 13-hour mission that included a brief excursion beneath the Thwaites Glacier ice front.

Four CTD casts were conducted on the approach from Pine Island Trough to the Thwaites Glacier Eastern Ice Shelf. On reaching the tip of the ice shelf early on February 26th we ran a multibeam bathymetry and sub-bottom profiler survey line southwards and then eastwards along the ice front as far as possible before encountering sea ice that been packed into the western part of the embayment in front of the Crosson Ice Shelf. Later that day we diverted about ten miles from the ice front to deploy an ocean glider, which was repeatedly diving in a small area until it was recovered on March 3rd, effectively behaving as a virtual mooring through most of the week.

A first core site in the area, near a former pinning point at the tip of the remnant Thwaites Glacier Tongue, was identified from the initial survey line. At CTD cast was conducted and then kasten, mega-, and jumbo (gravity) cores were collected at the site in the early hours of February 27th. Each of the coring devices over-penetrated, indicating very soft sediments that likely accumulated at a very high rate. A second megacore was deployed with ‘snow shoes’ attached to the frame to try to prevent it sinking in. Soon after the Palmer departed from this

site the wind speed increased to more 40 kts and for the next 12 hours it remained at a level that prevented any activity other than further survey. When the wind abated a CTD cast was conducted at the position where the glider had been deployed, which was close to the center of a NE–SW trending >1200 m-deep trough.

In the early hours of February 28th, cNODE acoustic transponders were deployed in the southeastern part of the embayment west of the remnant Thwaites Glacier Tongue in preparation for a Hugin AUV mission in the area. However, conditions had not improved sufficiently to allow deployment of the AUV, so we returned to the previous CTD location in the deep trough and collected kasten, mega-, and jumbo cores there. Following completion of coring operations at this site we returned to the start location of the planned Hugin mission and deployed the AUV. After it had been released, two CTD casts were conducted nearby for calibration. On March 1st, while the Hugin mission was in progress, closely-spaced CTD casts were conducted along a transect perpendicular to the ice front. Following a 13-hour mission conducting detailed survey of the seabed and deep water properties near the glacier front, the AUV was recovered in the afternoon. Later that day a second ocean glider was deployed in the area near the ice front, but it did not behave as expected and was recovered after only a few hours.

The jumbo corer and megacorer were deployed overnight on March 1st–2nd at a site close to the area the Hugin mission had investigated. In contrast to the earlier sites, which targeted high accumulation rate sedimentary successions, this site was chosen with the objective of dating grounding line retreat. Once the coring operations were complete we conducted two CTD casts along the axis of the main NE–SW trending trough that our initial multibeam bathymetry survey had revealed, followed by five CTDs on a transect across the northern part of the trough, centered around 74° 50’S. Time was taken during the transits between the CTD sites along the trough, and before conducting the transect across it, to fill remaining gaps in the survey coverage. Later on March 2nd multibeam bathymetry and sub-bottom profiler survey coverage was extended north of the tip of the remnant Thwaites Glacier Tongue before transiting to the southwest part of the area where there had been open water to the west of the Glacier Tongue to conduct a CTD transect across the southern part of the trough. Arriving in that area early on March 3rd we found a surprisingly high concentration of ice floes and icebergs, but we still managed to conduct four CTD casts along the planned transect.

After not having received any signals from the glider that had been deployed on February 26th for more than a day, contact with it was re-established on the morning of March 3rd and the decision was taken to recover it. It was located in an area where pancake ice had started to form and was successfully recovered. After recovering the glider we departed from the area west of the remnant Glacier Tongue, which was becoming increasingly difficult to work in due to encroachment of ice. We transited to a core site to the north of the Glacier Tongue, identified on survey data collected the previous day, where we collected a kasten core and a megacore. Leaving this core site we collected additional multibeam bathymetry and sub-bottom profiler data in the area north of the site, and then in the embayment between it and the Eastern Ice Shelf.

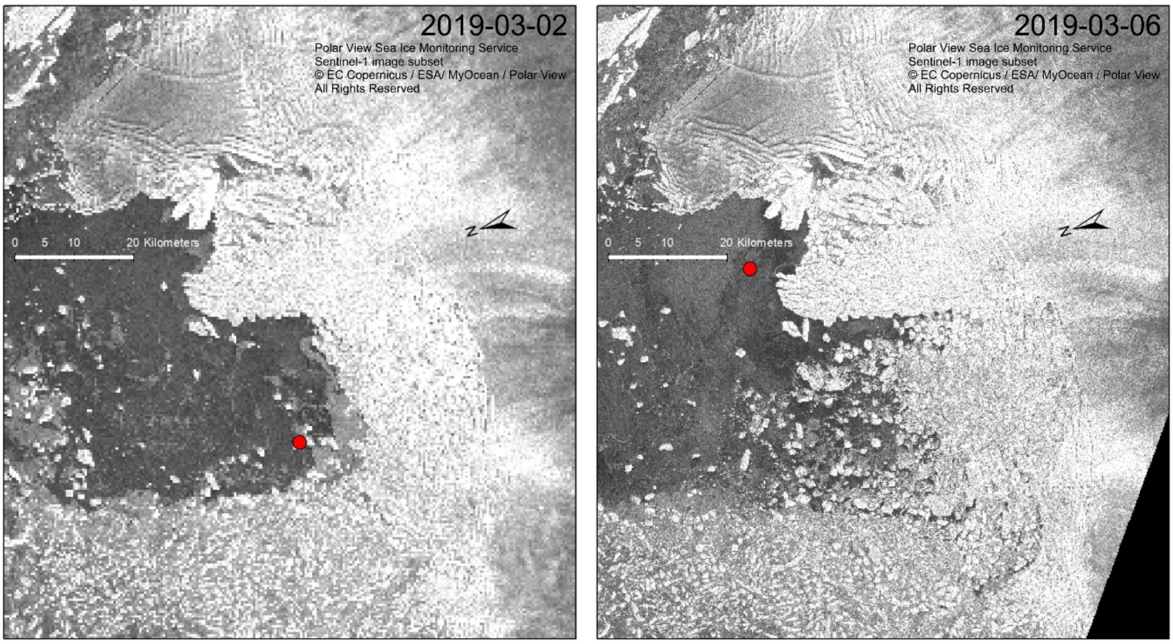

Figure 3. Sentinel-1 synthetic aperture radar images from March 2nd (left) and March 6th (right) showing the break-up of the ice mélange between the grounding line of Thwaites Glacier and the embayment where the *Palmer* was working from February 25th until March 3rd. Red-filled circles show the locations of the *Palmer* at the times the images were acquired.

3.5 From Thwaites Glacier to Pine Island Glacier and back

Satellite images revealed a spectacular break-up on March 2nd-3rd of the ice mélange between the grounding line of Thwaites Glacier and the embayment where the *Palmer* had been working at that time (Fig. 3). We had been surprised to see so much ice around us early on 3rd

March as we attempted to complete a CTD transect across a deep trough in the southern part of the embayment. Fortunately we completed the work we aimed to do in the embayment later that day and moved to work in the neighboring embayment between the remnant Thwaites Glacier Tongue and the Eastern Ice Shelf.

During the first part of the following week we conducted a broad suite of investigations in the embayment between the remnant Thwaites Glacier Tongue and the Eastern Ice Shelf, and extending into the area to its north. These included collection of multibeam bathymetry data over a continuous area of more than 400 km^2, four core sites, 10 full water depth CTD casts, a one-day deployment of an ocean glider in the embayment, tagging of two Weddell seals, and a 13-hour Hugin AUV mission that included a brief excursion beneath the edge of the Eastern Ice Shelf.

In the middle of the week we transited to Pine Island Glacier, collecting 5 full water depth CTDs on our route through Pine Island Bay. The first priority in this area was recovery and redeployment of two long-term moorings. The northern one was recovered but we could not find any evidence of the southern one, either from trying to make contact with it using acoustic signals or on the ship’s sonar systems. A new mooring incorporating components recovered from the northern site was redeployed near the location of the southern one. Before redeploying the mooring we conducted a transect of 14 full water depth CTD casts along the ice front and collected multibeam bathymetry data covering about 400 km^2 of seabed that has been newly exposed as a result of Pine Island Glacier calving events over the past two years.

Moving westwards again from Pine Island Glacier, we conducted 6 CTD casts along a transect across the coastal current that flows along the south side of Pine Island Bay, repeating a section from a previous cruise in order to examine temporal change and variability in the current. Further west again we collected sediment cores from two sites near where the edge of the Eastern Ice Shelf meets the grounding line. A few days earlier satellite images had shown a lead between the ice shelf and an area of dense sea ice coverage to its northeast. We had planned to enter the lead to conduct CTD casts along the edge of the ice shelf. Unfortunately, by the time we reached this area the lead had closed up, so we conducted CTD casts along the northeastern edge of the sea ice area instead.

3.6 Last actions and return to Punta Arenas

Before leaving the Amundsen Sea we decided to try and complete some of the work we had started on and around the small islands near the tip of Canisteo Peninsula on first arriving in the region. We started by conducting CTD transects parallel to the eastern flank of Pine Island Trough near the Brownson Islands, and then perpendicular to the trough approaching the Edwards Islands. Teams from the TARSAN and GHC projects once again used the zodiac boats to make landings on the Edwards Islands on March 11th. The TARSAN team attached satellite tags to six more Weddell seals while the GHC team measured and sampled from raised beaches on two of the islands. Initial results from one of the seals tagged during the previous visit had indicated unexpectedly deep water and unusual oceanographic conditions in Cranton Bay to the south of the islands. The following day we conducted multibeam bathymetry survey in that area, which had been beneath fast ice when we first visited the islands four weeks previously. Having located a bathymetric trough in Cranton Bay we conducted a line of CTD casts along it and collected a kasten core and a box core from a small basin on its flank. Our next intended targets were in Ferrero Bay, but at this stage that the worsening ice conditions convinced us to abandon plans for further work in the southern Amundsen Sea.

We had hoped to continue working in the Pine Island Bay region for about two more days. On the morning of March 13th, however, we noticed that the corridor between areas of 8–10 tenths ice coverage on the middle shelf, our exit route from the Amundsen Sea, was closing rapidly. This closure was due to southwestward drift of sea ice that had accumulated offshore from Thurston Island. During the previous night we had tried several different approaches to enter Ferrero Bay and found each potential route blocked by ice. The combination of this experience and the changing regional ice pattern persuaded us that it was time to leave the southern Amundsen Sea. For the rest of March 13th we tracked mainly westward to reach the corridor of less dense ice coverage, and even when we turned northwards during the night progress was slow at first. On March 14th, however, we made good progress and by evening we were encountering progressively less dense ice coverage in an area near the shelf edge.

A transect of eight CTD casts crossing the continental shelf edge and extending down to about 2000 m on the slope was started in the evening of March 14th. After this was completed, the remaining high priority task of the cruise was to try to recover an ocean glider that had been deployed in the Bellingshausen Sea during the previous cruise. During the transit

eastwards to its last reported location we stopped once, late on March 15th, to repeat the deep CTD cast that had been the first one of the cruise. The *Palmer* reached the last reported location of the glider in the afternoon of March 17th and began searching for it. Unfortunately, despite stopping at numerous locations to try to contact it using acoustic signals, in this area and along its likely drift path to the west, the glider was not found. One more transect of eight CTD casts crossing the continental shelf edge and extending down to about 2000 m on the slope was conducted in the afternoon and evening of March 18th. On the morning of March 19th a couple multibeam bathymetry lines were run to increase the data coverage around a proposed International Ocean Discovery Program drill site on the lower continental slope. However, the weather conditions compromised the data quality was and soon after midday the survey was terminated to start transit to Punta Arenas.

Weather conditions improved and were generally favourable during the transit back to Punta Arenas. The *Palmer* tied up at Muelle Prat at 17:00 local time on March 24th.

4 Activity Reports

4.1 Multibeam and sub-bottom profiler surveys

Ali Graham and Kelly Hogan

4.1.1. Objectives

The main objectives of marine geophysical work on cruise NBP19-02 were: (1) to provide characterization of the bathymetry and sub-surface geology, including the mapping of sea-floor geomorphology and the imaging of sub-bottom architecture; (2) to map the detailed bathymetric pathways for warm water accessing Thwaites Glacier sub-ice shelf cavity; (3) to resolve landforms and features that record recent and ancient grounding, unpinning, and grounding line retreat of the ice margins in the eastern Amundsen Sea embayment; (4) to provide critical site survey information for the collection of sediment cores and the interpretation of potential ice, climate, and ocean records held within them.

Shipboard geophysical data collection consisted of swath bathymetry mapping using a hull mounted Kongsberg EM122 deep-water multibeam echo-sounder, and sub-bottom profiling using a separate hull-mounted Knudsen Chirp 3260 3.5kHz sub-bottom profiling system.

The two sounders were operated simultaneously and near-continuously during the cruise, and as such can be considered a single geophysical survey. The sites in which data were acquired can be sub-divided (by operational order) into five work areas: (i) Demas Ice Tongue, (ii) Ferrero Bay, (iii) Cranton Bay, (iv) Thwaites Glacier ice front, and (v) Pine Island Glacier ice front. Data were recorded additionally on passage from Punta Arenas to and from the Amundsen Sea embayment, and between working areas whilst conducting science in the region. Furthermore, data were acquired on a routine basis to/from Rothera base during the medical evacuation that interrupted science activities mid-way through the cruise.

Prior to the expedition, the Amundsen Sea embayment had been well mapped in the middle and inner shelf areas of Pine Island Trough/Bay, and in coastal regions east of Burke Island, as the result of a multi-national focus on the region that has persisted for more than a decade. However, significant areas of the inner shelf in front of Thwaites Glacier remained entirely uncharted prior to NBP1902. Datasets from past UK, US, German, and Swedish expeditions to the region were

compiled into a single grid before our arrival in the Amundsen Sea. This grid included the most recent MeBo drilling expedition to Pine Island Bay (PS104; Gohl *et al.* 2017), as well as unpublished data from a RV *Nathaniel B. Palmer* cruise (NBP19-01) that obtained limited multibeam bathymetry in the central Amundsen Sea embayment immediately prior to our own cruise. Data from NBP1901 were edited, cleaned and processed by THOR shipboard scientists and incorporated into planning maps during initial passage southwards. Supporting the high-resolution multibeam datasets were bathymetric compilations from the Amundsen Sea published by Nitsche *et al.* (2007), sub-ice bathymetry published by Millan *et al.* (2017), in addition to ice-front and grounding line positions taken from MacGregor *et al.* (2012) and Millilo *et al* (2019). Collectively, these data were used for planning, scientific navigation, and survey design during NBP19-02.

4.1.2. Work at sea

The NBP's EM122 multibeam echo sounder was used near-continuously for the duration of the cruise. The EM122 system emits 432 beams (at 1˚ resolution) at 12 kHz, providing a practical spatial resolution between ~10-100 m and a swath width of up to a maximum of ~5 times the survey water depth (maximum 140 degrees athwartship). Dual swath mode was fixed to afford greater along-track resolution. Beam raypaths and seafloor depths were calculated in near-real-time using sound velocity profiles (SVP's) derived from conductivity-temperature-depth (CTD) and expendable bathythermograph (XBT) casts, the majority collected during cruise operations (see Table of SVPs used during cruise; Table 1).

Table 1. Summary table of Sound Velocity Profiles (SVPs) used on NBP19-02, as recorded in the cruise underway log. N.B. Coordinates are ship position when SVP was applied.

SVP	Source	Latitude	Longitude	Date/Time applied	Multibeam survey	Line number
TD_0003_XBT01	XBT01	60° 02.0265	84° 59.1147	05-FEB-2019 01:59	NBP1902a	0014
Lev-20190205-1701	Levitus	62° 09.1724	87° 57.8568	05-FEB-2019 17:29	NBP1902a	0029
TD_00034_XBT02	XBT02	65° 27.0694	92° 34.8225	06-FEB-2019 16:30	NBP1902a	0052
TD_00035_XBT03	XBT03	69° 30.5220	99° 47.8008	07-FEB-2019 23:42	NBP1902a	0087
SV_nbp1902_001	CTD001	70° 44.3848	102° 15.4623	08-FEB-2019 16:59	NBP1902a	0101
SV_nbp1902_002	CTD002	72° 27.6	103° 53.5	09-FEB-2019 23:00	NBP1902a	0128
SV_nbp1902_003	CTD003	73° 12.582	104° 15.96	10-FEB-2019 16:10	NBP1902b	0016
SV_nbp1902_006	CTD006	73° 48.6763	106° 32.8230	14-FEB-2019	NBP1902b	0085

				18:58		
SV_nbp1902_007	CTD007	73° 33.6644	106° 09.8896	15-FEB-2019 17:06	NBP1902b	0100
SV_nbp1902_001	CTD001	71° 08.9355	107° 10.4993	16-FEB-2019 08:34	NBP1902c	0115
SV_nbp1902_003	CTD003	69° 33.4438	100° 46.41	16-FEB-2019 04:05	NBP1902c	0135
TD_00036_XBT04	XBT04	69° 11.1713	92° 18.0	17-FEB-2019 18:04	NBP1902c	0149
TD_00037_XBT05	XBT05	68° 47.3131	84° 55.7826	18-FEB-2019 06:43	NBP1902c	0162
TD_00038_XBT06	XBT06	67° 56.2725	70° 16.5689	19-FEB-2019 08:36	NBP1902c	0187
SV_nbp1902_008	CTD008	68° 06.9351	73° 19.1913	22-FEB-2019 05:38	NBP1902c	0207
TD_00037_XBT05	XBT05	68° 14.3581	75° 26.0331	22-FEB-2019 09:30	NBP1902c	0211
TD_00036_XBT04	XBT04	69° 9.0366	90° 16.0366	23-FEB-2019 11:58	NBP1902c	0237
SV_nbp1902_001	CTD001	70° 11.09	105° 37.16	24-FEB-2019 15:15	NBP1902c	0264
TD_00039_XBT07	XBT07	72° 50.11	107° 58.38	25-FEB-2019 12:51	NBP1902b	0289
SV_nbp1902_007	CTD007	73° 43.1030	106° 25.7	25-FEB-2019 18:45	NBP1902b	0295
SV_nbp1902_009	CTD009	74° 12.0209	105° 33.9725	26-FEB-2019 00:02	NBP1902b	0299
SV_nbp1902_010	CTD010	74° 22.9376	105° 04.9146	26-FEB-2019 00:36	NBP1902d	0002
SV_nbp1902_011	CTD011	74° 32.14	105° 23.633	26-FEB-2019 02:54	NBP1902d	0007
TD_00042_XBT08	XBT08	74° 51.6527	107° 12.2603	26-FEB-2019 17:54	NBP1902d	0017
SV_nbp1902_017	CTD017	74° 57.55	107° 20.298	28-FEB-2019 07:38	NBP1902d	0047
SV_nbp1902_030	CTD030	74° 52.2102	107° 12.3138	02-MAR-2019 22:53	NBP1902d	0083
SV_nbp1902_038	CTD038	74° 55.4819	106° 06.9461	04-MAR-2019 08:14	NBP1902d	0116
SV_nbp1902_050	CTD050	74° 47.438	104° 05.0727	07-MAR-2019 09:56	NBP1902d	0162
SV_nbp1902_056	CTD056	74° 09.404	101° 36.197	08-MAR-2019 07:58	NBP1902d	0175
SV_nbp1902_081	CTD081	74° 37.7234	104° 53.1459	11-MAR-2019 02:05	NBP1902d	0230
SV_nbp1902_087	CTD087	73° 53.5597	103° 06.7621	11-MAR-2019 18:43	NBP1902d	0244
SV_nbp1902_090	CTD090	74° 01.552	102° 55.057	12-MAR-2019 05:13	NBP1902d	0253
SV-nbp1902_099	CTD099	71° 03.5513	107° 00.8215	15-MAR-2019 01:11	NBP1902d	0316
SV_nbp1902_105	CTD105	70° 05.9335	90° 50.6154	17-MAR-2019 01:36	NBP1902a	0175
TD_00037_XBT05	XBT05	68° 56.0267	86° 21.0344	19-MAR-2019 12:25	NBP1902a	0236
TD_00044_XBT09	XBT09	76° 59.8965	64° 33.8628	20-MAR-2019 22:40	NBP1902a	

Multibeam swath bathymetry and Chirp profiler surveys were focused at each of the work regions shown in Figure 4. Where sea-bed features or targets of interest were identified, blocks of the sea floor, normally consisting of multiple overlapping swaths, were mapped out. In the following sections, figures 5–9 illustrate the new data coverage.

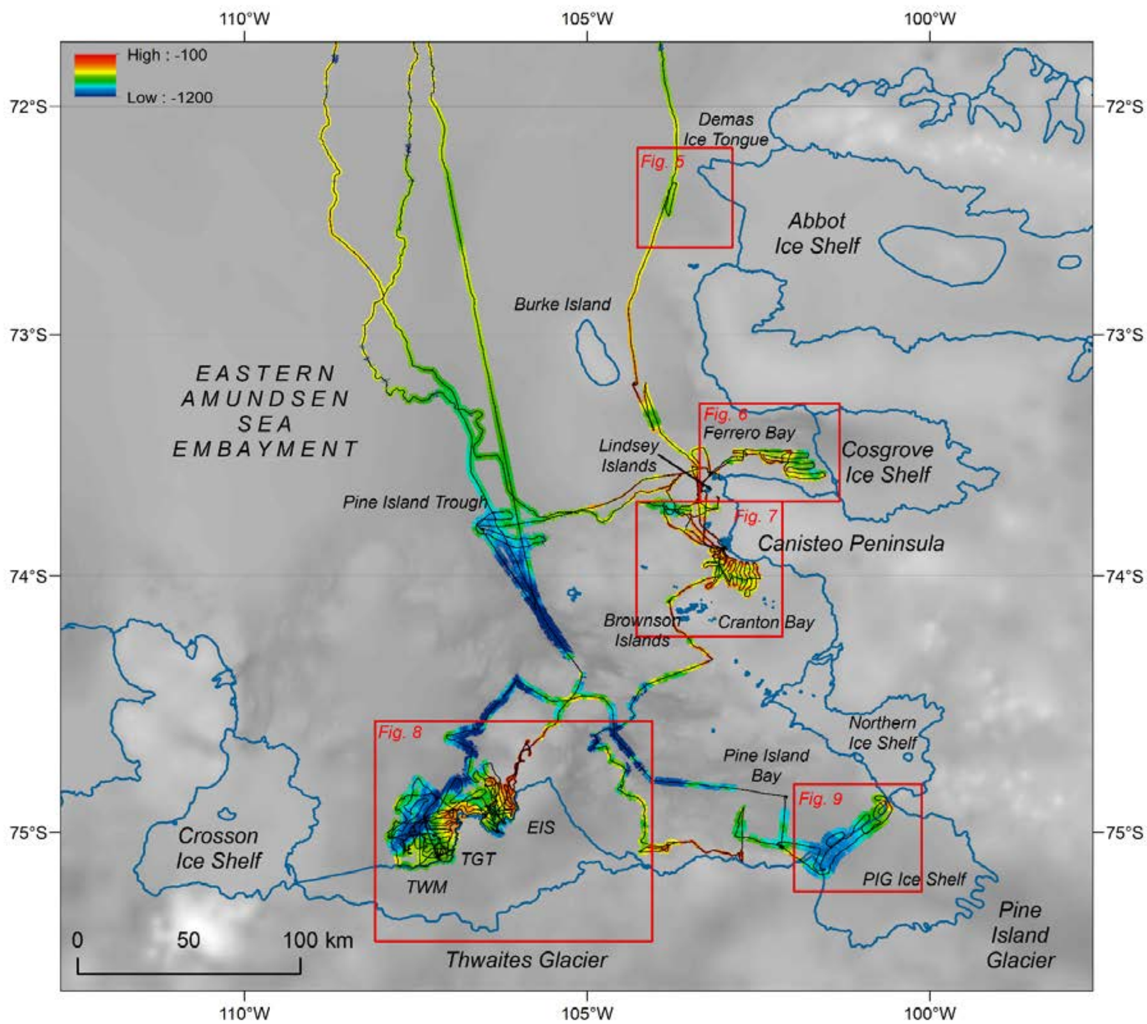

Figure 4. Location map outlining the five working areas for cruise NBP19-02 in the eastern Amundsen Sea embayment. Locations of subsequent figures shown by red boxes. TWM: Thwaites Western Mélange; TGT: Thwaites Glacier Tongue; EIS: Eastern Ice Shelf; PIG: Pine Island Glacier.

In total, approximately 10,500 line-kilometers of swath bathymetric data were collected during the cruise (up to and including 19th March 2019). The process of ping-editing to remove anomalous depths was carried out whilst onboard, using the mbeditviz module within the open-source sonar

processing software MB-system (Linux/Unix). The majority of the data collected had been fully processed at the time of writing this report, with the exception of survey data recorded on transit legs to and from Punta Arenas/Rothera.

In the SIS interface onboard, multibeam data were logged to a survey name labelled alphabetically and incrementing by line number from zero. However, multibeam data were subsequently grouped by 'day' on the NBP and hence logged and processed in this format. A summary of the SIS surveys is nevertheless provided in Table 2.

Table 2. EM122 surveys as recorded to the SIS operator interface on NBP19-02.

Survey name	**Work area**	**Start Date/ Time (UTC)**	**Start Time of Last Line (UTC)**	**Total lines**
NBP1902a	Passage to/from Punta Arenas	04 FEB 2019/ 12:45 15 MAR 2019/03:45	09 FEB 2019/23:28 22 MAR 2019/06:34	1-129 130- 304
NBP1902b	Initial shelf work in the Amundsen Sea; work on return to Amundsen Sea	10 FEB 2019/00:31 25 FEB 2019/06:39	15 FEB 2019/06:26 26 FEB 2019/03:33	0-92 282-300
NBP1902c	Medical evacuation to/from Rothera	15 FEB 2019/10:58	25 FEB 2019/06:33	94-280
NBP1902d	Thwaites Glacier, PIG, and Cranton Bay work	26 FEB 2019/01:33	15 MAR 2019/02:14	0-318

Order of acquisition: NBP1902a Lines 1-129, NBP1902b Lines 0-92, NBP1902c Lines 94-280, NBP1902b Lines 282-300, NBP1902d Lines 0-318, NBP1902a Lines 130-304

4.1.3. Rationale, work, and preliminary observations

(i) Demas Ice Tongue survey

The first activity carried out by the THOR project team on breaking through sea-ice in the northeastern Amundsen Sea embayment was to survey and subsequently select a site for coring in the trough that extends westwards from the Abbot Ice Shelf, adjacent to the Demas Ice Tongue (Fig 5). The site was important because the history of the ice tongue, which is pinned on a shallow sea-bed high, is not known. The location may serve as a useful analogue for locations around the floating margins of Thwaites Glacier where it is pinned to shallow sea-floor ridges, particularly with respect to the sedimentary environments and processes encountered there.

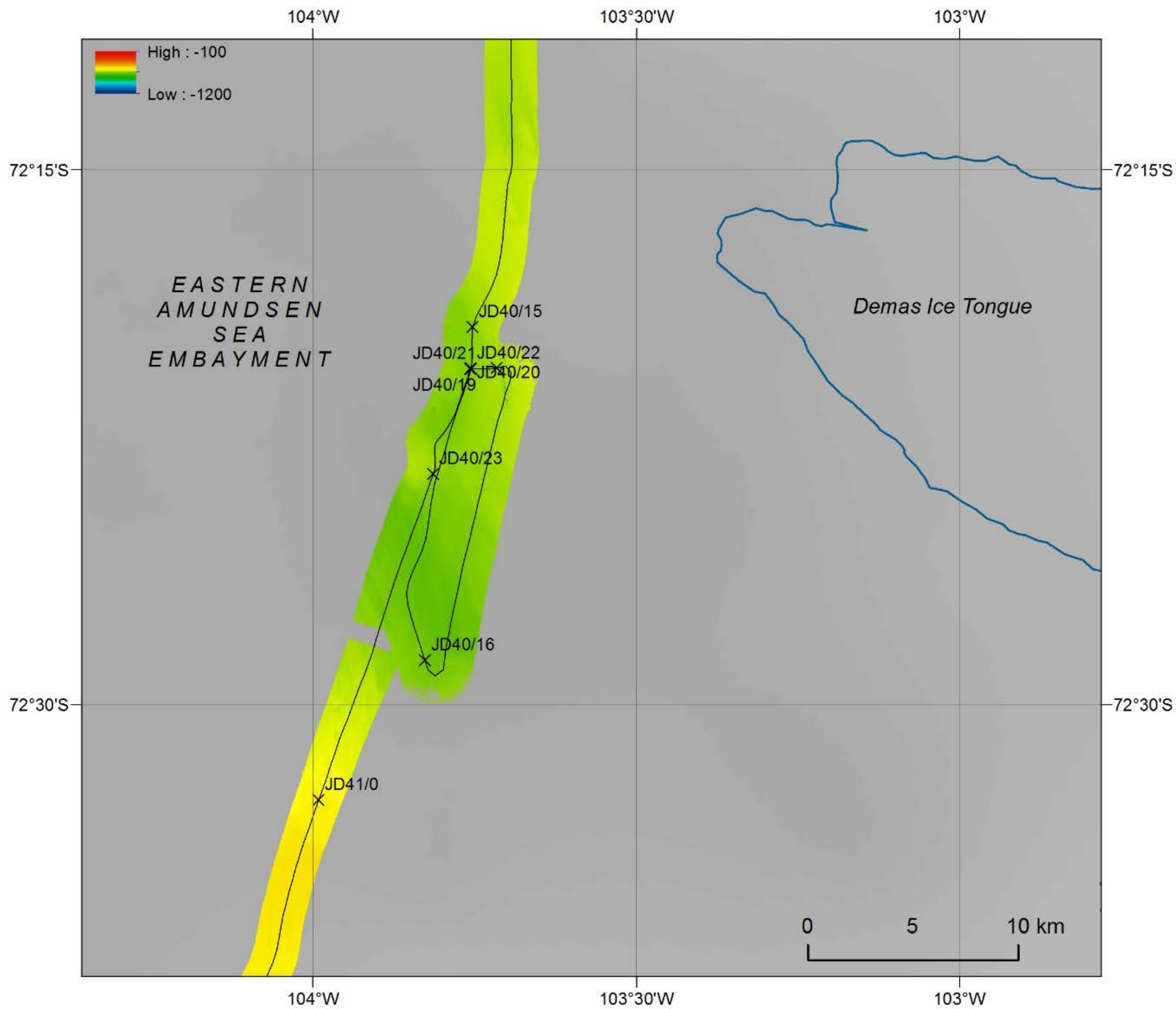

Figure 5. Multibeam survey tracks and coverage in the area west of the Demas Ice Tongue.

Two overlapping swaths c. 16 km in length were collected to the southwest of Demas Ice Tongue across a trough c. 600-700 m deep. Subglacial bedforms streamlined in the direction of ice flow were imaged on the multibeam data, but superficial sediment cover was only observable on Chirp profiles towards the northern end of the track where the bathymetry shoaled. The trough extending away from the ice shelf appears to lack a thick postglacial sedimentary drape suggesting low rates of sedimentation, at least in this part of the shelf.

(ii) Ferrero Bay

The northern half of the embayment in front of the Cosgrove Ice Shelf, referred to as Ferrero Bay, was surveyed during an earlier cruise of the NBP in 2000, and more extensively during RV *Oden* cruise 09-10. Cores were recovered on both cruises, although only material from the most recent of these have been worked upon and published. The bay is surprisingly deep in its innermost part – c. 1200 m – and landforms on existing bathymetry show evidence for streamlining by subglacial erosion, possible modification in the form of subglacial meltwater flow, as well as a strong east-west geological fabric. Furthermore, it has been shown that, today, Circumpolar Deep Water (CDW) moves onto the continental shelf via the Abbot Trough and one branch of it circulates clockwise underneath Cosgrove Ice Shelf forming a strong outflow to the south. Paleoceanographic records obtained from cores in deep parts of the bay show a history of ice shelf presence and absence, and forcing by ocean changes through the Holocene.

The CDW that enters onto the shelf near Abbot Trough and branches into Ferrero Bay eventually makes its way to Thwaites Glacier, which means the area is an important one to study because it has the potential to record CDW incursions in an 'outer-shelf' setting that relate directly to Thwaites forcing. It is a site where records of recent ocean change can be obtained to compare with more proximal Thwaites paleo-records, and can serve as a microcosm of the Thwaites Glacier system because of the strong circulation in the cavity.

Having deployed teams to work onshore at the Lindsey Islands, we had the opportunity to undertake marine geophysical survey into and out of Ferrero Bay overnight on Julian Day (JD) 42 and into JD43. Although weather conditions affected the quality of the incoming multibeam signal, the data collected from the embayment survey expand the sea-floor coverage in the southern half of the bay (Fig. 6). Preliminary observations reinforce the notion that the submarine landscape reflects phases of substantial glacial erosion, and that meltwater has probably exploited existing structural weaknesses to excavate the sea-floor fabric in the past. Chirp profiler data indicate that any sedimentary basins are localized and poorly penetrated by the sounder. Through most of the survey area the sub-bottom profiler data image bedrock at the sea-floor and do not resolve a thick overlying hemipelagic drape. A key objective of our mapping was to survey into the corner of the embayment and core where the outflow was expected and a small, persistent polynya has recently

been observed. Unfortunately, the ship had to turn back to the islands before completing the survey at the ice-shelf edge due to time restrictions. A Hugin AUV mission collected very high-resolution geophysical data at the mouth of Ferrero Bay which will highly complement any results from the shipborne sonar work. However, at the very end of the cruise we ran short of time to revisit the Cosgrove Ice Shelf area to map the southeast corner of the embayment and obtain additional cores. Completing the ice-shelf front mapping and collection of cores at the ice front ought to be an objective of the next THOR expedition to the region in 2020.

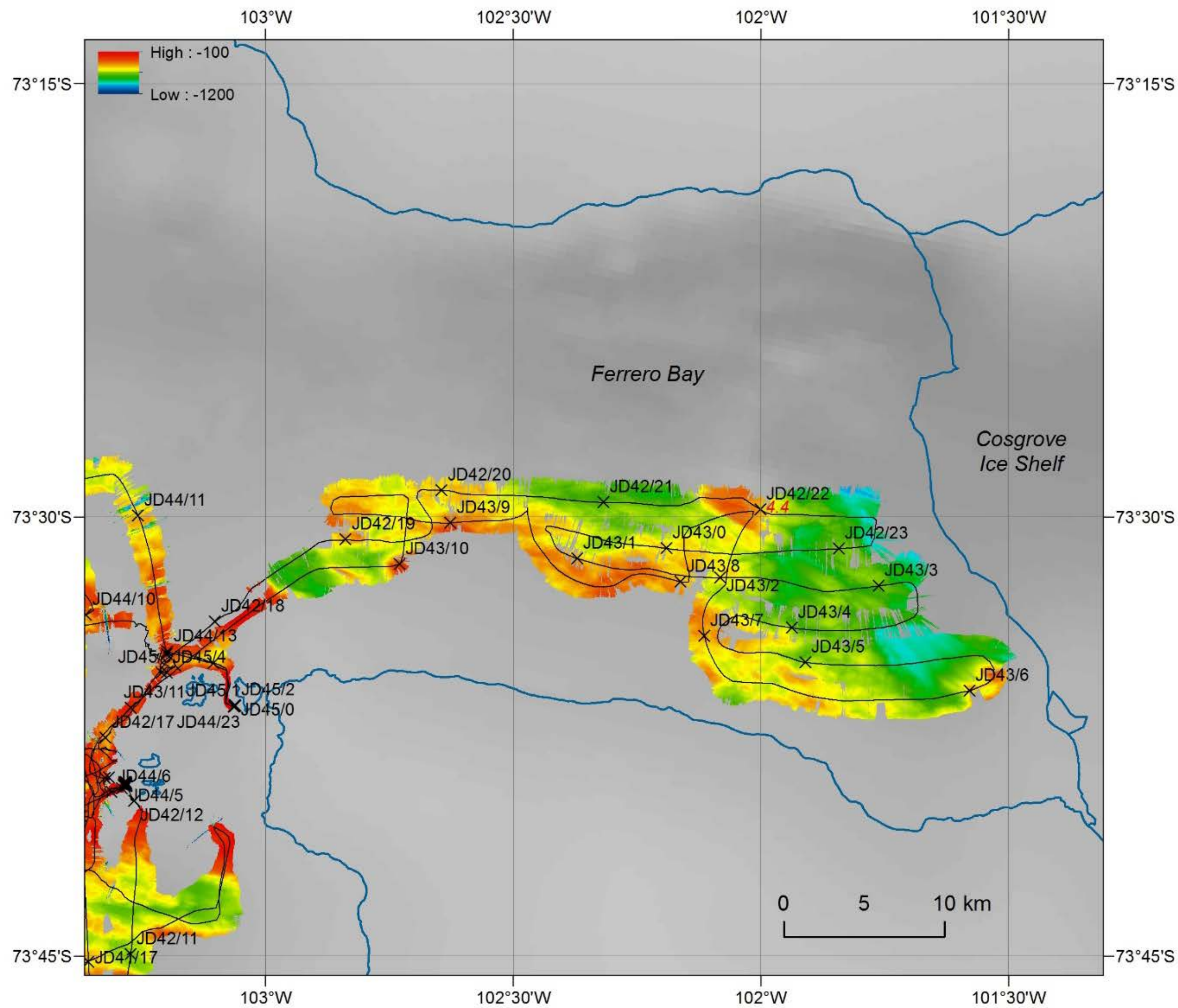

Figure 6. Multibeam survey tracks and coverage in Ferrero Bay, seaward of the Cosgrove Ice Shelf.

(iii) Cranton Bay

Cranton Bay, at about 20 nautical miles long and wide, lies south of the Canisteo Peninsula at the eastern end of the Amundsen Sea (Fig. 7). The southern limit of the bay is formed by the Backer Islands and by the northern ice shelf, which separates this bay from inner Pine Island Bay. The region is poorly mapped but interesting for a number of reasons: 1. it was likely an inter-ice-stream zone through large parts of the last deglaciation when the ancestral Thwaites Glacier was more expanded. 2. It may also be a possible route through which CDW reaches major ice streams in the southern ASE. 3. Dense, saline shelf waters may also exist at depth in isolated but shallow deeps within the bay. 4. Sea-ice covered areas may be productive high-accumulation sedimentary zones from which cores can record past phases of ice cover and absence. Carbonate material is also likely to be well preserved in these sequences given their relatively shallow depths.

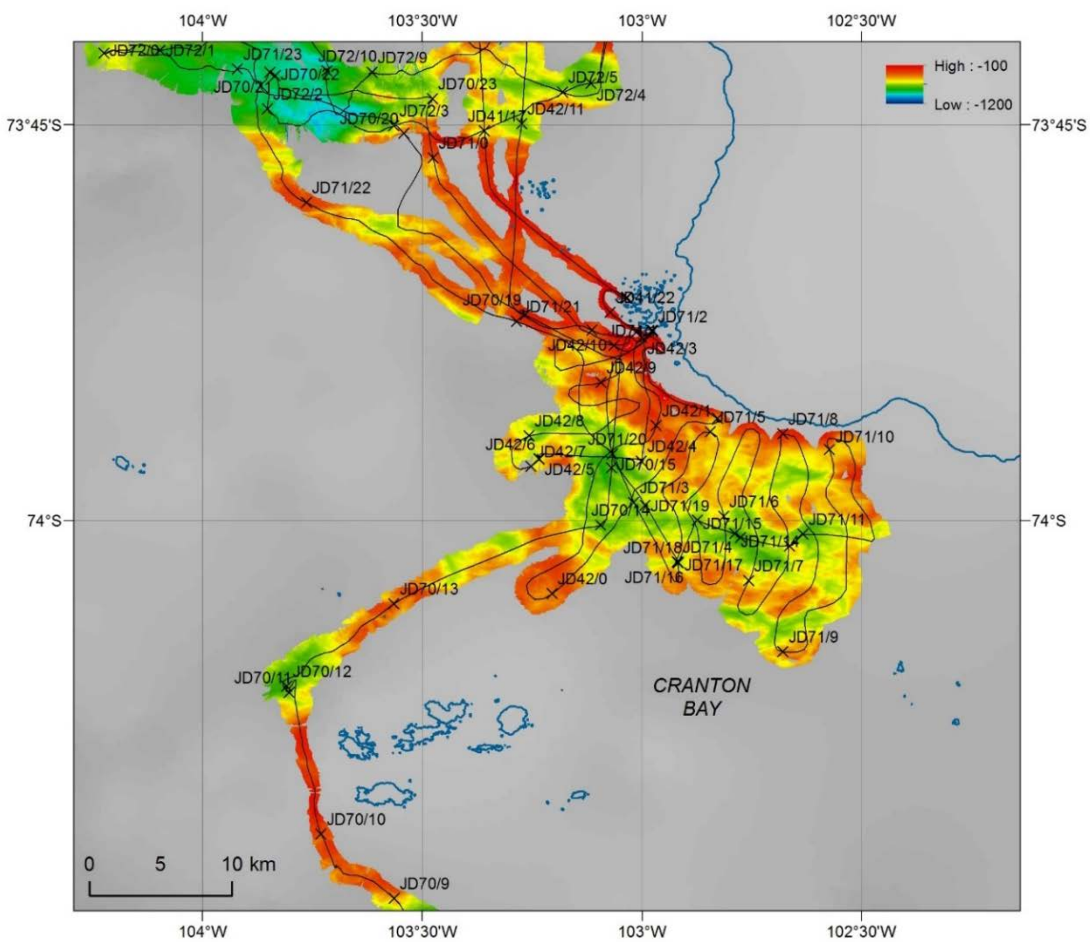

Figure 7. Multibeam survey tracks and coverage in the area of Cranton Bay, south of Canisteo Peninsula.

On NBP1902, significant multibeam coverage was obtained to the east, and southeast of Burke Island, and in the Cranton Bay area where fast ice is often persistent. Three separate phases of survey work mapped three different targets within this region. The first obtained data in and around the Burke Island area, supplementing multibeam data acquired during PS104 in 2017; the second acquired marine geophysical data along the edge of a fast-ice zone that extended westwards out of Cranton Bay; a third period of work, at the very end of the cruise, mapped a continuous zone of sea floor south of Canisteo Peninsula to investigate isolated deeps in the ocean floor and their possible interconnections. The latter was supplemented by CTDs and a single coring station.

From work east of Burke Island, it has been possible to resolve new information on the relative history of paleo-ice flow from landform swarms that overprint one another. There is clearly further work to be done on the interaction between subglacial meltwater erosion and subglacial geology, as well as the nature of transitions in basal thermal regime beneath past ice sheets grounded on the continental shelf. The mapping across Cranton Bay also shows, once again, how structural geological processes are a first order control on the landscape and its long-term evolution. Chirp sub-bottom profiler data show sporadic pockets of sediment between 2-10 m overlying bedrock in the survey area.

(iv) Thwaites Glacier ice front

A principal objective of the THOR field season was to chart the sea floor in the region in front of Thwaites Glacier to provide vital boundary conditions that are currently absent, and deliver a map that will form the foundation for a wealth of science that will follow within the ITGC program. Specifically, THOR was keen to search for evidence of past and present ice shelf grounding and unpinning, any geomorphic records of past stability and/or change in Thwaites Glacier, and to map the inlets and passageways that deliver warmer deep water to the ice shelf and its cavity.

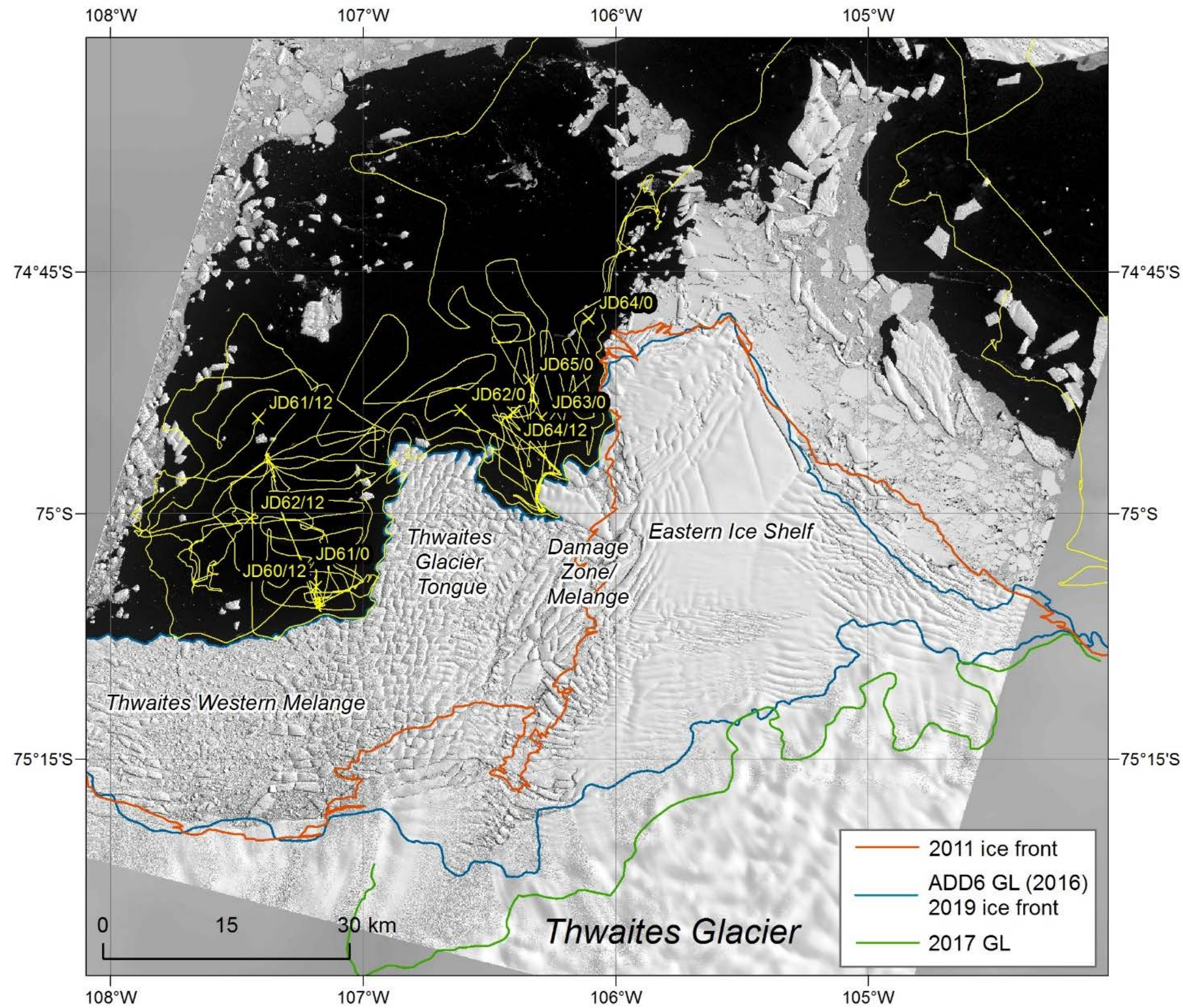

Figure 8. Multibeam survey tracks in the area of Thwaites Glacier ice front. Image is a pan-sharpened georectified visible image acquired on 15th February 2019 with the OLI sensor on the Landsat 8 Earth Observation satellite. Grounding lines (GL) from 2016 (blue; Antarctic Digital Database v. 6) and 2017 (green; Milillo et al. 2019) are shown, alongside ice front positions for 2011 (red; MacGregor et al., 2012) and present-day (February 2019; unpublished).

Unusually ice-free conditions in front of the floating ice shelf this season meant that our objective could be met in full (Fig. 8). Our initial tracks into Thwaites Glacier at the end of February followed the ice shelf edge from the tip of the Eastern Ice Shelf, past the Thwaites Glacier Tongue, and across the western embayment until we came face-to-face with fast-ice/mélange packed against the front of the Crosson Ice Shelf. Multibeam bathymetry and Chirp profiler data were recorded during our navigation along the ice edge, giving modern ice-shelf front bathymetry, and in many places imaging the sea-floor for several kilometers underneath the floating margin. An

interesting by-product of this mapping approach was that the outermost port-side beams often returned echoes from the floating ice-shelf edge. Because we also recorded water column data through this survey, it was possible to pick both the ice shelf draft and the shape of the ice front at regular intervals along the Thwaites Glacier ice front. Subsequent mapping efforts were focused in the embayment in front of western Thwaites ice mélange. Data were recorded along the margin of the ice mélange in front of the Crosson Ice Shelf, and latterly, the sea bed was surveyed comprehensively to the north and west of the Thwaites Glacier Tongue. Particular attention was placed on mapping the pinning point at the northwest corner of the protruding Glacier Tongue, and on the large, deep, northeast-southwest striking trough, as well as deep offshoots from it, that are the major topographic features in the vicinity.

Sedimentary environments appear diverse in the Thwaites inner shelf region. In the NE-SW oriented trough Chirp profiles image a >10 m-thick acoustically-stratified package of sediments. This unit is pervasive but thins to the flanks of the trough and is absent across outcropping highs within the trough. In the western ice-proximal corner of our survey in front of the Thwaites Western Melange, thick stratified 'drift-like' deposits were imaged at c. 650 m in a sub-trough that branches off the main channel in a south-easterly direction. The unit here is isolated to one flank of the channel and has a discrete mounded geometry in plan view. Elsewhere, in front of Thwaites Western Melange we imaged heavily streamlined topography that appears to form broadly-continuous ramps that may be a succession of till sheets formed at one or more past grounding lines. Although this terrain is largely acoustically opaque, till sheets do appear to blanket and partially bury underlying bedrock highs in the ice-proximal region.

To avoid encroaching ice which preceded the breakout from the western Thwaites mélange that occurred at the very beginning of March, we moved east to survey in the middle embayment between Thwaites Glacier Tongue and the Eastern Ice Shelf. Here, complete coverage of the open shelf was obtained. We imaged a number of dislocated troughs and shallower pinnacles that may have been recent or more ancient locations of ice-shelf pinning. Having completed survey across the accessible areas close to the Thwaites ice front, we moved eastwards to Pine Island Glacier. We would return to the eastern margin of the Eastern Ice Shelf later on in the cruise, to attempt to map into a lead that had opened up behind the fast-ice in its southeastern corner. However, the

lead had closed on our arrival and no further mapping was conducted around the Thwaites ice margin as a consequence.

The survey data collected on NBP1902 resulted in **the first comprehensive map of the ocean floor and sub-ice shelf bathymetry at the Thwaites Glacier ice front**; a major achievement for the cruise party, and the ITGC program as a whole.

(v) Pine Island Glacier ice front

Pine Island Glacier remains a locus of dramatic and important changes in the Amundsen Sea embayment, reflecting the wider patterns and forcings that are also leading Thwaites Glacier to change its behavior. In recent years, the sea bed in Pine Island Bay has been comprehensively mapped (see Nitsche et al., 2013 and Arndt et al., 2018). However, major calving events in two successive years had opened up a sector of sea floor more than 10 km wide spanning the entire ice shelf front where sea-floor bathymetry was poorly known.

Whilst undertaking CTD transects along the PIG ice shelf edge, THOR completed mapping of the sea-bed in front of Pine Island Glacier on an opportunistic basis (Fig. 9). Two reciprocal lines were planned but the amount of retreat in the ice margin was substantial - more than first anticipated - which required us to modify our tracks to incorporate a third line in several locations in order to achieve complete overlap with existing datasets.

The new data at PIG show a continuation of the deep and heavily streamlined sea floor that forms the floor of the Pine Island Trough along which the glacier currently flows. To the northern end of the survey, sea bed highs were imaged that form the submerged extensions of Evans Knoll, and which are likely to be important structures that control the dynamics of contemporary iceberg calving at PIG.

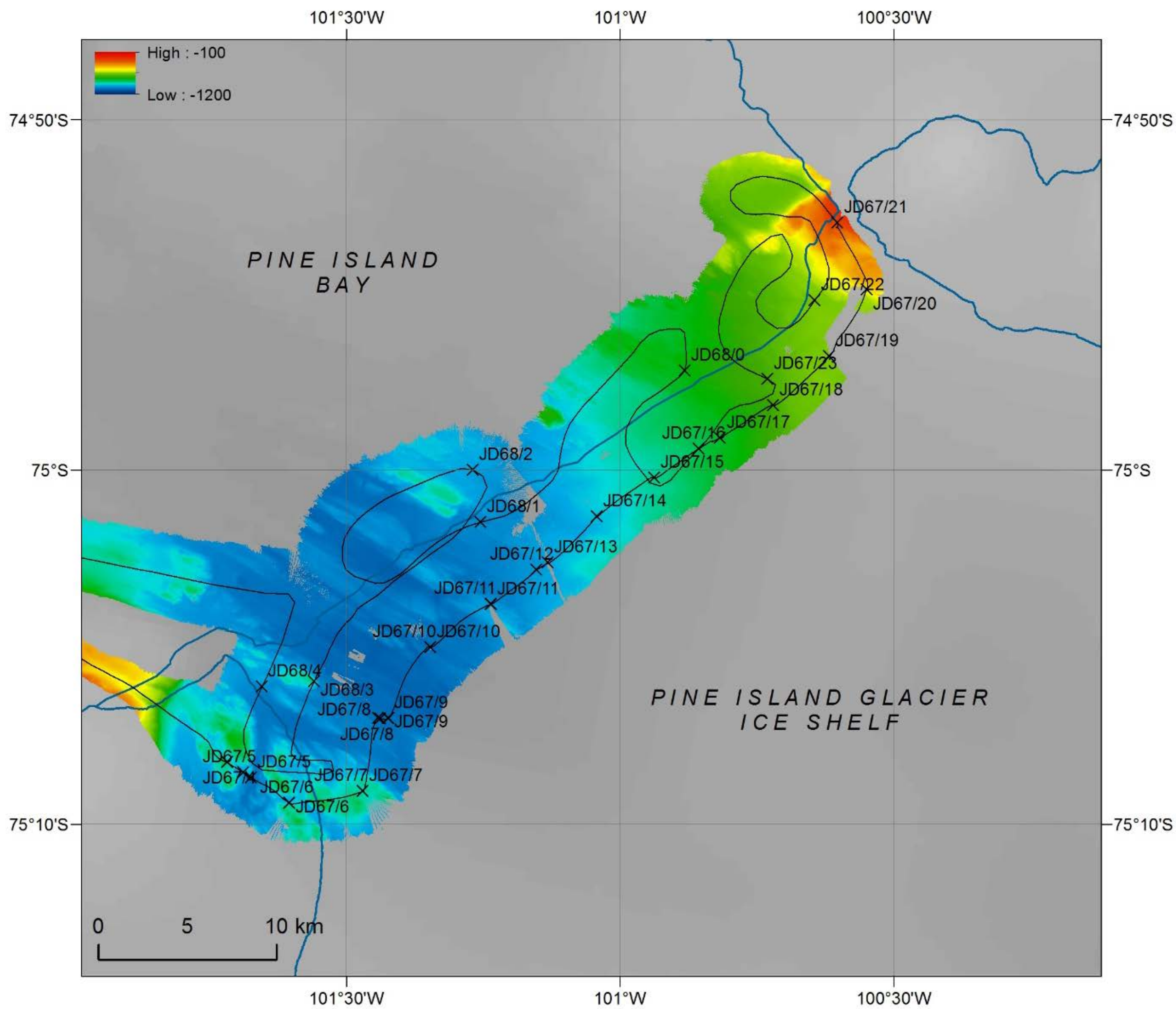

Figure 9. Multibeam tracks and coverage along the front Pine Island Glacier Ice Shelf. 2016 ice edge shown in blue.

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4.2 Sediment coring strategy

Rebecca Totten Minzoni

Three study areas were cored during the NBP19-02 cruise: the southern Amundsen Sea offshore Thwaites Glacier (Fig. 10), Cranton Bay south of the Canisteo Peninsula (Fig. 11), and the northern Amundsen Sea proximal to the Demas Ice Tongue of the Abbot Ice Shelf (Fig. 12).

Four type of coring device were used during the cruise: kasten corer (KC), megacorer (MC) jumbo piston corer in gravity mode (JPC) and box corer (BC). See coring operations section for further details of how each of these devices was used and how they performed.

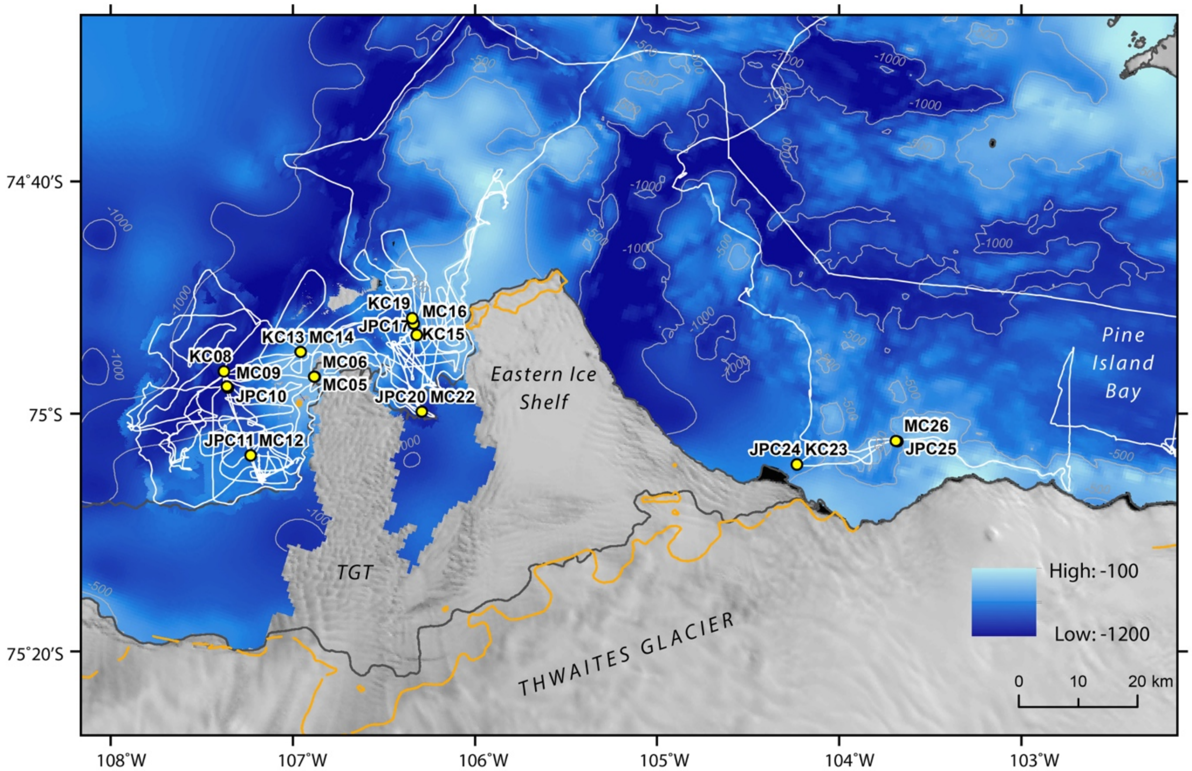

Figure 10. Locations of core sites offshore from Thwaites Glacier.

The area proximal to Thwaites Glacier was the main focus of this project, and 24 cores targeted a diverse range of bathymetric settings around Thwaites Glacier. Cores KC08, MC09, and JPC10 targeted a sedimentary basin within the uncharted deep western trough west of the Thwaites Glacier Tongue. The water depth in the deep trough site exceeded 1100 mbsl. Similarly, JPC20 and MC 22 targeted a small sedimentary basin within the middle trough between Thwaites Glacier Tongue and the Eastern Ice Shelf, in a water depth of ~1000 mbsl. The deep site was targeted to build a preliminary sedimentary model for Thwaites Eastern Ice Shelf area that can be used in the THOR sub-ice shelf mission for the 2020 season.

The primary target of the Thwaites Glacier study area is small sedimentary basins on bathymetric highs, where carbonate preservation is expected to be fair. Prior studies in the Amundsen Sea have shown that carbonate shells and foraminifer tests dissolve at depths greater than ~750 mbsl, due to an elevated lysocline in the cold deep water. In order to enable radiocarbon dating of carbonate material, sites shallower than 750 mbsl were preferentially chosen. We further targeted sites within

a range of depths at which Circumpolar Deep Water is expected to flow into the region, from 350 to 700 mbsl. The bathymetric high off the western pinning point, where the Thwaites Glacier Tongue is grounded today, receded during historic time. The Thwaites Glacier Tongue has receded during historic time from a western pinning point on a bathymetric high around its present northern tip. Cores KC04 (see position of MC05 on map), MC06, KC13, and MC14 targeted the recently ice free area directly seaward of the modern ice shelf pinning point at ~450 mbsl water depth. MC06 and KC04 were collected from a linear channel-like basin on the bathymetric high.

To explore the relative stability and past glacial history of the western and eastern pinning points, the bathymetric high upon which the Thwaites Eastern Ice Shelf is currently pinned was also targeted for sedimentary archives. The eastern pinning point is characterized by a number of stepped basins, and for this reason we were able to sample a transect from the modern ice margin to the middle trough. JPC 17 and KC 18 (failed) sampled a high plateau ~500 mbsl that may have been eroded by recent ice shelf pinning at this location. KC15 and MC 16 sampled a small basin ~550 mbsl, proximal to the modern ice margin. KC 19 sampled a deeper minibasin on the slope of the pinning point, to the northeast of KC15 and MC16, at a water depth of ~700 mbsl. The comparison of sites along this transect will enable us to reconstruct the recent history of thinning and retreat of the Eastern Thwaites Ice Shelf to its current position. Moreover, the sampling of sedimentary products of Thwaites Glacier and surrounding ocean, recorded in this archive of cores along a range of water depths, will aid in reconstruction of oceanography and potential controls on the past and present stability of Thwaites Glacier.

Lastly JPC25 and MC26 were taken after a long effort to approach the eastern side of the Eastern Thwaites Ice Shelf. Sea ice prevented sampling of sites proximal to the ice shelf. Based on geomorphic evidence of streaming from the multibeam survey, JPC25 and MC26 (~550 mbsl) were collected in a region where the expanded Thwaites Glacier and Pine Island Glacier paleo-ice streams may once have converged. This site will be used to study the history of interactions between these two major ice streams.

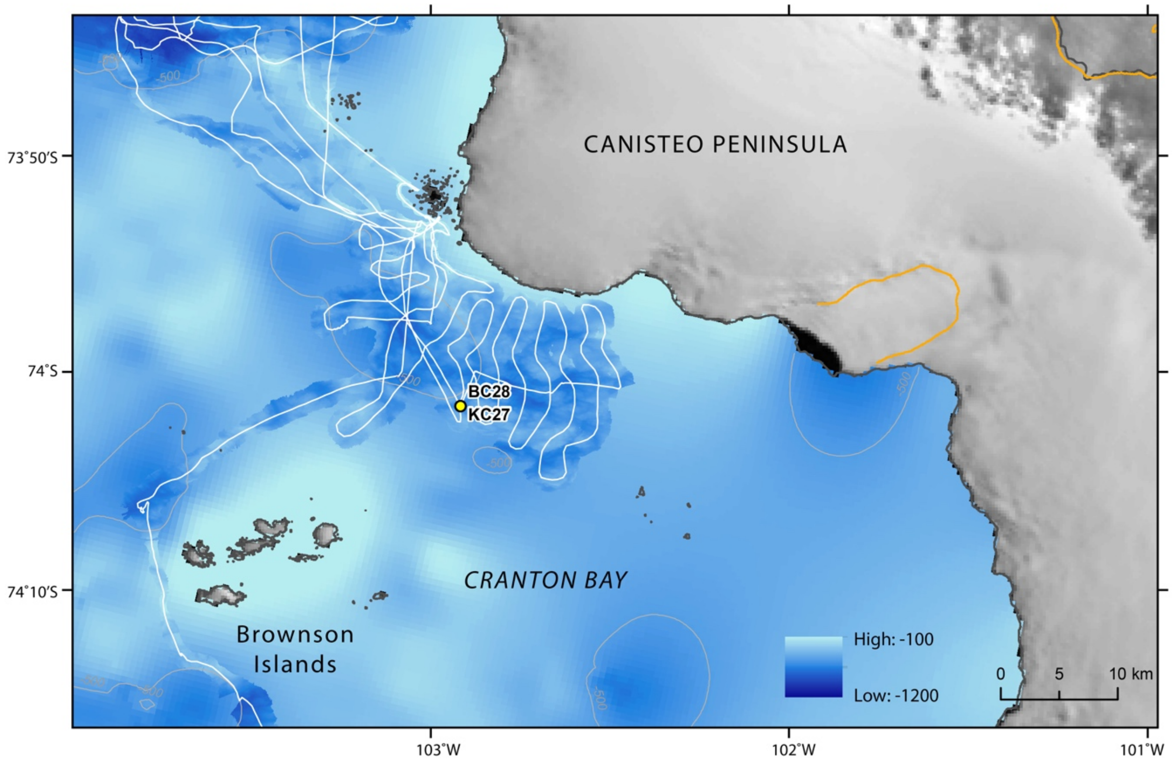

Figure 11. Location of sediment cores KC27 and BC28 in Cranton Bay, eastern Amundsen Sea.

The second study area in Cranton Bay, south of Canisteo Peninsula, was explored during operations near the Edwards Islands. Preliminary data from seal tags and melting of fast ice in this area during the duration of NBP19-02 suggest that Cranton Bay contains much colder deep water than the areas explored near Thwaites Glacier. Therefore, cores KC27 and BC28 were collected to sample a record of this cold shelf water mass, which will be important for calibrating the geochemical and microfossil proxies that will be applied to the sediment record of Thwaites Glacier history.

The third study area in the northern Amundsen Sea Embayment is located seaward of the Abbot Ice Shelf and Demas Ice Tongue. This basin was chosen en route to the primary study area near Thwaites Glacier, as a site where coring gear could be tested. Importantly, cores KC01 and MC02 provide a sedimentary archive with which to reconstruct the glacial history of the Abbot Ice Shelf, which has yet to be studied. This site can lend useful comparison to similar ice shelves of the eastern Amundsen Sea (Cosgrove Ice Shelf, Minzoni et al., 2017), to the recent and Holocene

records of the Pine Island Glacier Ice Shelf (Hillenbrand et al., 2017; Smith et al., 2017), and to the forthcoming glacial history of Thwaites Glacier.

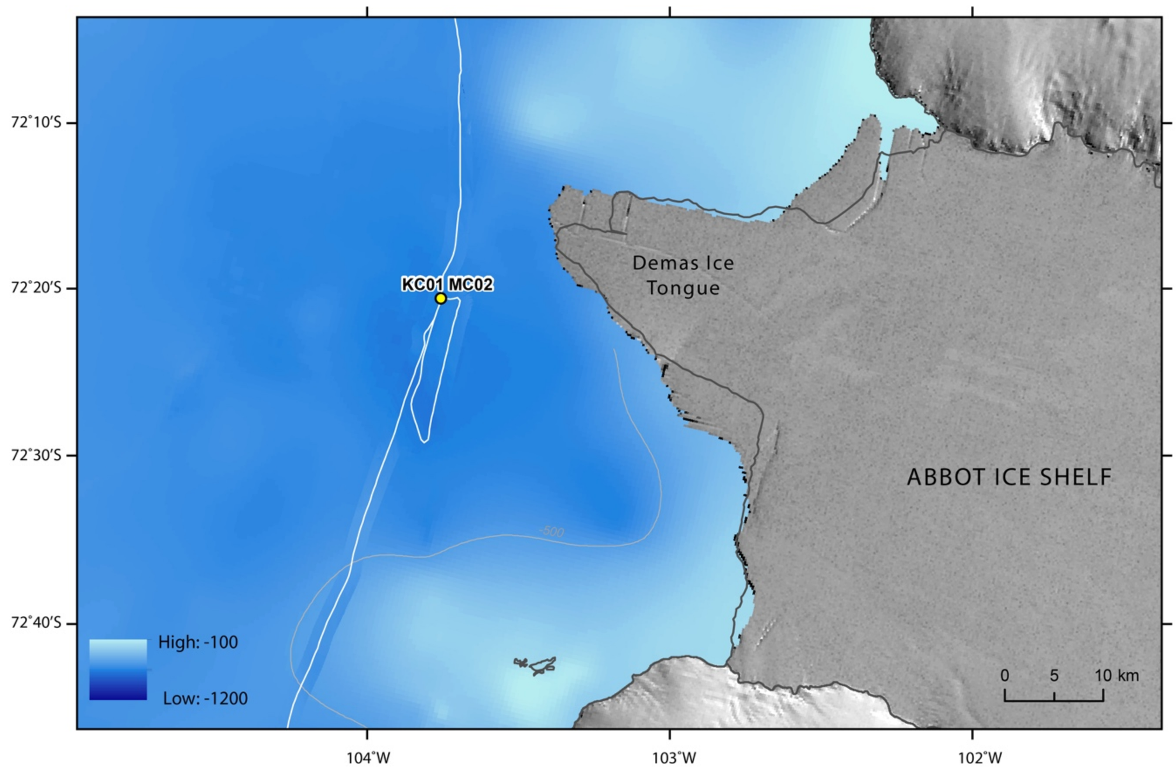

Figure 12. Location of KC01 and MC02 offshore from the Abbot Ice Shelf and the Demas Ice Tongue, eastern Amundsen Sea.

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4.3 Sediment core processing and archiving

Rebecca Totten Minzoni

When the cores arrived on deck, the KC's and JPC's were transported to the aft dry lab to be processed, while the MC's were transported the walk-in fridge (set at +3°C) to settle out before processing. The Box core was processed on the aft deck near the aquarium room.

4.3.1 Kasten Cores

The Kasten cores were opened and cleaned using plastic spatulas, then photographed alongside color scales and tape measure. Shear strength (in KPa) was measured every 10 cm in each core using the British Antarctic Survey-owned Torvane, and the same two people measured shear strength for each core throughout the cruise to maximize consistency. All lithological descriptions were conducted by Dr. Totten Minzoni; descriptions are based on sediment color (Munsell Color Chart), texture, fossil content, and sedimentary structures. Descriptions can be found in Appendix A3 of this report.

Kasten Cores were then sampled in a specific order, according to collection sensitivity. Several analyses are planned for these cores and proper care must be taken for each, necessitating a pre-determined order to sampling. First, rhizons were inserted into the Kasten Cores for collecting pore water samples at critical intervals. This typically took 1.5 to 3.5 hours to collect the necessary 2 mL of pore water. While the pore water was collecting, other samples were taken in the area to the side or above or below the rhizons, which require an undisturbed 2 cm^3 volume of sediment from which to draw water.

Next, ~20 cc samples for trace metals and Be-10 analysis were collected every 10 cm downcore with plastic spatulas and placed into 4 oz whirl paks. This typically took 2 to 3 hours due to the

small spatula size and difficulty to extract soupy sediment. Therefore, we highly recommend plastic sediment plugs to improve sampling efficiency during next year's cruise. This will cut down the need to clean spatulas between samples, which was conducted with ethanol solution and a kimwipe.

Samples of ~20 cc volume were then taken for Pb-210 and grain size analysis. Sampling intervals were determined by hypothesized sediment accumulation rates, which are likely different for each core site. Where sediment accumulation is expected to be high, samples were taken continuously in the upper 40 to 80 cm, and every 10 cm below that. Sampling resolution never exceeded 2 cm in core depth. These samples will also be used for water content when measured at the University of Houston, and pre-weighed bags were used until they were gone, at which point whirl paks and ziplock bags were used.

Samples of ~20 cc volume were taken every 10 cm for carbon and nitrogen isotopes and microfaunal and microfloral analysis at the University of Alabama.

Smear slides sampling important transitions, representative units, and individual laminations were studied by the THOR team onboard to aid core descriptions. Approximately 250 smear slides were made during the cruise, permanently mounted with optical adhesive, and will be analyzed at the University of Alabama.

All extra sample was either placed into large cups to be sieved at 63 microns onboard or placed into plastic bags to be sieved later at the University of Alabama. These samples typically span either 8 cm or 4 cm in core length and will aid in the search for carbonate material for radiocarbon dating.

Additionally, samples were taken from the freshly opened core tops for foraminiferal analysis and dyed with Rose Bengal. Samples were dyed with Rose Bengal at the following intervals within every Megacore: 0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-5 cm, 7-8 cm, and 10-11 cm. Samples were also dyed in the very top of Kasten cores where no Megacore was collected to evaluate quality of the core and preservation of the sea floor.

All sieved samples were photographed using a Dinolite digital microscope and transferred into 10 mL vials (for rose Bengal samples) and into 4 oz whirl pak bags for large sieved samples.

4.3.2 Archiving

Next, the Kasten Core was cleaned off again using spatulas to create a smooth, even surface. An archive core was taken from each Kasten core by inserting 1 m-long square clear plastic Kasten Core trays and removing the trays using a piano wire and spatulas. These clear square archive trays have a cutter on the liner where it is inserted into the sediment core, and minimal disturbance of the archive was achieved. Two 3/62" holes were drilled into either end of the archive trays to improve archive quality. The holes allow air to escape the tray and prevent deformation of the sediment, especially where water-laden, soft muds tend to squeeze out of the upper core. The archives were labeled, photographed, and wrapped heavily in Saran wrap for transport to the Oregon State University Marine Geological Repository Facility in Corvalis, Oregon for permanent storage.

4.3.3 Megacores

Water samples were taken from the Megacore tubes using small tubing. Water samples were sampled into one 2 mL vial, one 20 mL vial, one 100mL vial, and one 250 mL bottle that was poisoned with mercuric chloride. Headspace was avoided due to potential exchange with gas that can affect isotopic composition of the water. The surface seafloor sediment was immediately sampled for biomarkers and clay minerals.

The MC's were then extruded in 1 cm intervals using an extrusion platform onboard. Slices were taken in each interval for live foraminifera, Pb-210 and grain size, carbon and nitrogen isotopes and diatoms, and trace metals and Be-10.

When more than two core tubes were taken, archive(s) were made of the Megacore using a 2" clear plastic liner. MC-06 and MC-09 do not have archives because there was not enough sample for all the proxies and an archive.

4.3.4 JPC

The Jumbo Gravity Cores (JPC's) were extruded and cut on deck in 1 m sections using a rotary cutter. The sub sections were then carried into the aft dry lab and labeled. Small scrapes from the

ends of the sections were collected for description and smear slides. The core section ends were capped and taped for shipment to the Antarctic Research Facility, where they will be opened and archived.

4.3.5 Box Cores

A water sample was immediately taken from the Box Core, because water was seeping out of its base. Two damaged Megacore tubes were salvaged and cut, then shaved at the base to make a cutter. The MC tubes were pushed into the Box Core and a piston was tightened in the top of the tube to create a strong vacuum. The MC tubes were pulled out of the Box Core then placed on the MC extruder to subsample at cm intervals, as described above.

To archive the Box Core, 2” clear plastic liners were inserted vertically into the Box Core, labelled and sealed.

4.3.6 Kasten Core Descriptions

All lithological descriptions of kasten cores were conducted by Dr. Totten Minzoni; descriptions are based on sediment color (Munsell Color Chart), texture, fossil content, and sedimentary structures. Core disturbance is noted where present. Descriptions can be found in Appendix A3 of this report.

4.4 CTD casts and water sampling

B.Y. Queste, Y. Zheng Y and R. Totten Minzoni

4.4.1 CTD profiling

CTD casts are the workhorse of physical oceanography. These provide wide spatial coverage with relative ease, even in rough conditions. The objectives of CTD sampling on this cruise were:

(i) To map the general hydrographic conditions on the shelf for the 19/20 season to contribute to analysis of interannual variability and to provide context for the higher resolution observations.

(ii) To serve as calibration for the Hugin, gliders and seal tags.

(iii) To provide hydrographic context at each core site.

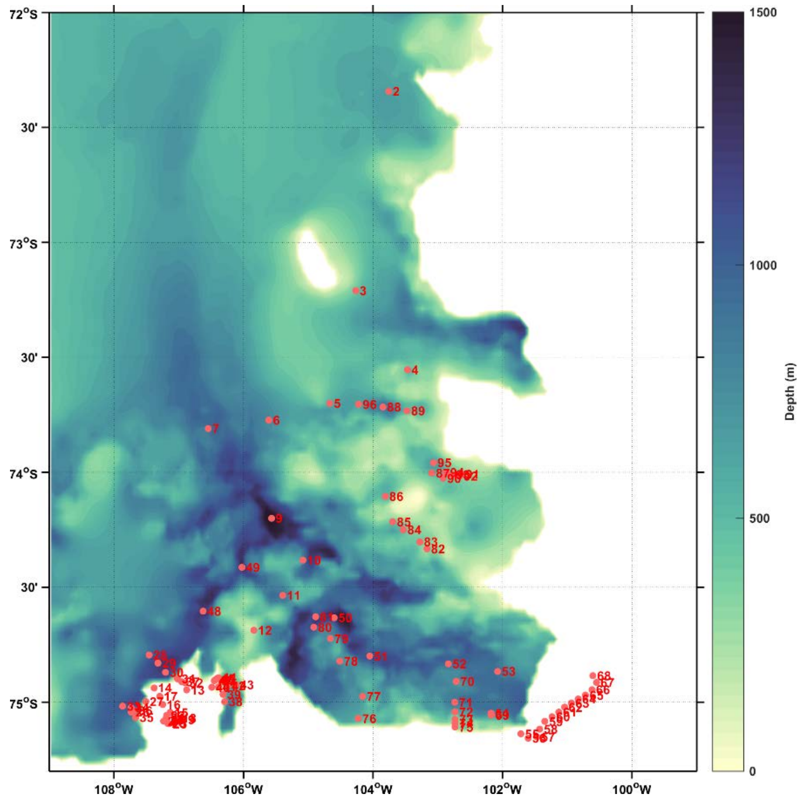


Figure 13. Locations of CTD casts in the Amundsen Sea Embayment.

(iv) To obtain a small number of high-resolution sections coupled with the ship's ADCP to calculate geostrophic velocities across coastal and slope currents and across ice fronts.

4.4.2 Water sampling

A total of 26 salinometry samples were taken from the RVDAS flow-through for calibration along with 236 from CTD casts for CTD calibration. 40 eDNA samples were collected and

filtered for the Swedish team and 117 chlorophyll samples were filtered onto GF/F for calibration of the CTD fluorometer.

Sampling protocols are detailed in Appendix A5.

4.5 Glider activities

B.Y. Queste

4.5.1 Overview (inc. recoveries)

Due to delays shipping gliders SG620 (UEA) and SG621 (Caltech), they were not onboard the previous cruise (NBP19-01) and could not be deployed as planned. These two gliders were loaded onto the Gould after the departure of NBP19-01 and then transferred to the NBP near the end of NBP19-01. Andy Thompson deployed SG621 in the Bellingshausen to complement SG539's deployment at the start of NBP19-01. SG621 was kept onboard to be deployed during NBP19-02.

We had three successful glider deployments with SG620, listed below. SG621 was deployed in western Thwaites but rapidly recovered due to very poor communications. Following a post-recovery inspection, I can only assume the antenna took a hit during the initial recovery in the Bellingshausen (cf. Glider deployment table in Appendix A6), causing the antenna element to fall out of alignment. The connectors were clean and dry, and all parameters onboard were fine; communications were good before recovery but were poor during self tests on deck and during the NBP1902 deployment.

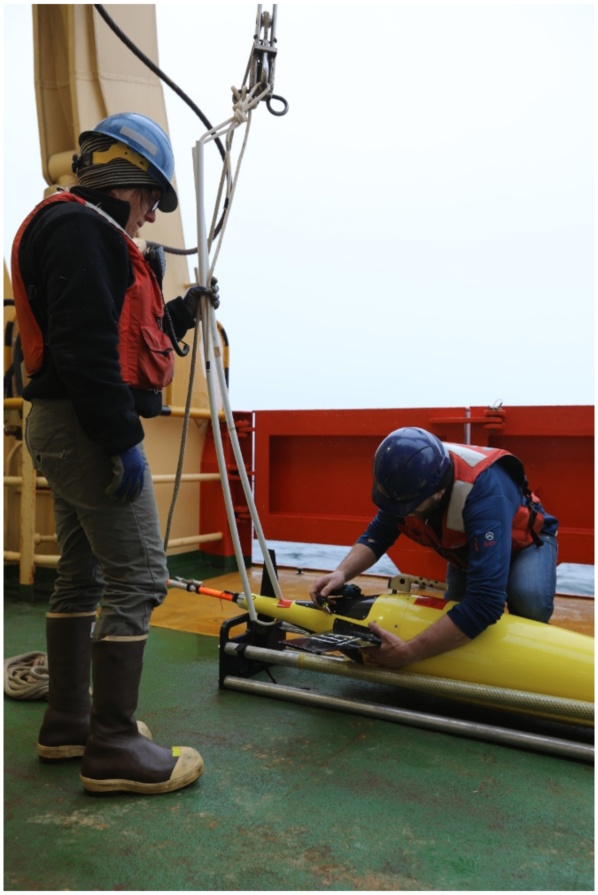


Figure 14. Preparation for glider deployment.

SG620 was equipped with a standard flow through Seabird CT cell, an Aanderaa 4330F optode, and a Wetlabs Ecopuck (Chlorophyll, OBS 700 and OBS 470).

4.5.2 Deployment and recovery procedures

All gliders underwent self tests before and after each deployment. SG620's configuration was changed before the first deployment to correct a bad .cnf configuration for the wetlab sensor. All gliders were also used to collect 5 minutes of data from the Aanderaa optode while on deck to correct for drift using the atmospheric correction method used on bio argo floats.

All deployments and recoveries were done from the starboard A-frame. With the ship's low freeboard and smaller starboard A-frame, it was considered both easier and much quicker to deploy this way rather than moving small boats from the helo deck to the main deck, then to the water, then craning the glider onto the small boat (as deployments of the small boat with a glider inside were discouraged). Visibility from the bridge was sufficient for good positioning during recovery at the bridge wings, and the grating over the thrusters provides a good level of safety (for the glider) if the thrusters need to be turned on while the glider is nearby.

Deployments were done using a pelican hook and tug line, accompanied by the usual dual PVC pipe and rope system used by UEA (Fig. 14). This was a 2 to 3 person operation, with Bastien Queste guiding the glider out of the cradle and then using a fender, while one MT guided the A-Frame and provided support when lifting the glider. A second MT or scientist was there to remove the cradle and bring the fender when necessary while keeping eyes on the tug rope. Deployments were generally completed in sub-15 minutes.

Figure 15. Glider recovery from starboard rail.

Recoveries were also very rapid, generally taking less than 30 minutes, including positioning the ship. The glider was captured using the rigid hoop and lasso on the extendable pole, then walked back to the starboard A-frame. A butterfly knot was tied on the line and attached to a quick-hook at the end of the A-frame wire. An oversized pulley and smooth block was used to allow the line to be pulled through the pulley in order to get the glider over the railing.

4.5.3 Mission 1: Burke to Canisteo

The first deployment lasted 4.5 days, and has calibration CTDs at both ends of the transect. The glider surveyed a section extending from the southern tip of Burke Island to the Lindsey/Schaeffer Islands where the ship was waiting to recover following 4 days at the islands. A compass calibration was done early on to ensure good DAC. The glider collected 49 dives of good data.

4.5.4 Mission 2: Thwaites West

The second glider deployment was west of the Thwaites Ice Tongue and was cut short as ice started to form rapidly in the area. Recovery happened with urgency as the antenna was icing up and spotting it was becoming increasingly difficult. During recovery it slipped under larger pancakes several times making it hard to grab. Surprisingly, the recovery loop was robust enough to push through 3 cm thick pancakes. The glider collected 48 dives, however the conductivity data is poor compared to nearby CTDs. I suspect the conductivity cell was damaged either during the first recovery when the CT cell was pushed against the ship, or if water froze inside during deployment/recovery or while at the surface. Conductivity showed a big offset during the first few dives and an even bigger offset after being sat on the surface following an impromptu $RECOVERY. I believe this wasn't due to ice clogging the cell as it was present from the start in the third deployment.

The $RECOVERY was caused by the glider's $NOCOMM_ACTION which was set to trigger $RECOVERY after reaching $N_NOCOMM of failed communications. This is a crucial parameter when flying gliders near ice and should never be set to trigger recovery. If the glider goes into recovery under thick ice, there is no process allowing it to escape again. Same goes for

$STOP_T and $N_DIVES. These general safety parameters are useful when there are no surface obstacles and communications are reliable. In the Amundsen, they're a great way to lose a glider.

4.5.5 Mission 3: Thwaites North

The final mission was cut short due to increasing ice in the region and decreasing comms quality. The glider only obtained 14 dives near the second Hugin deployment site. This deployment also showed a very clear error in conductivity.

4.5.6 Salinity and pressure correction

Comparison of CTD and glider data showed that calculation of a scale factor which matches up glider conductivity to CTD conductivity for deep warm waters reliably adjusts the whole water column. This provides a robust and consistent correction to the glider salinity data.

SG620 also seems to report significantly different pressure readings to the CTD. To match the depth of the warm water core, glider pressure readings had to be multiplied by 1.05. This required further investigation.

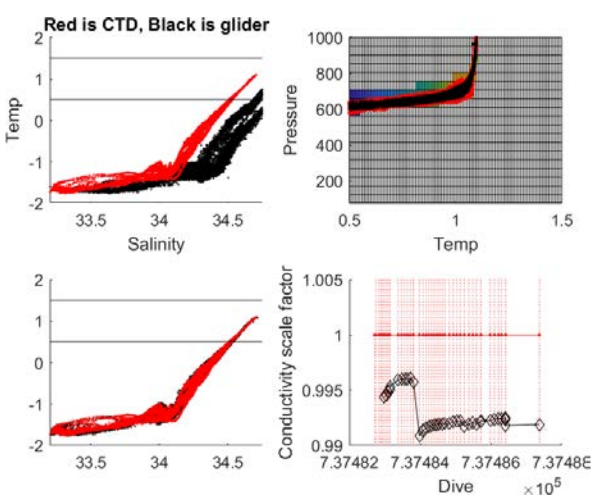


Figure 16. Comparison of CTD and glider data in Thwaites West area.

Fig. 16. shows the correction scale factor applied to conductivity during SG620's second mission. We can clearly see the two offsets present during the mission. Interestingly, we see a gradual decrease of the first error while the second error remains constant throughout the rest of the mission. The top left panel shows the offset between the CTD (red) and the glider (black) while the bottom left panel shows the same post-correction.

4.5.7 SG539 Search operation

SG539 was reported missing in the Bellingshausen Sea on the 9th of March. It subsequently managed to call in again on the 13th and provide an extra GPS fix dated from the 9th of March. The $RECOVERY code provided by the glider indicates the glider went into recovery mode after missing $N_NOCOMM,2 calls. As the glider was under ice it was unable to obtain adequate GPS fixes or communicate (with the exception of the truncated call on the 13th).

The NBP went to the glider’s last known position and began an acoustic search, using the ship’s Benthos DS-7000 acoustic transponder. We surveyed a fan like pattern following the ice edge in the direction the glider was estimated to have drifted. We surveyed 10 hours outwards and then 10 hours back pinging the transponder every 15 seconds. Every 5 nm, the ship was stopped completely, and all sources of sound switched off to assess if we could hear a longer range signal.

The acoustic transponder seemed to perform well and filtered noise well while we were in open water. We were able to run the transponder at high gain settings (Setting: 7) in these conditions. However, when the ship was in the ice, gain on the transponder had to be reduced (Setting: 3-4) as noise from the ice caused too many false positives. No signals resembling what we would expect from the glider were encountered during the entire search period. Ice conditions were generally clear outside of the ice limit (< 1/10), but suddenly changed to 10/10 cover inside the ice zone. There was no intermediate zone and everything was compacted southward. Ice conditions consisted of a mix of 1-2 year old sea ice, with new large pancakes covered with ~10 cm of snow, large growlers and bergy bits. It is very likely that we came near the glider but the acoustic transponder is not sufficiently strong to provide a clear signal with all the background noise generated by surface ice.

4.6 Hugin AUV missions

A.K. Wåhlin

In total 9 missions were conducted with the Hugin AUV (Appendix A7), two of which went underneath Thwaites ice shelf. The missions were gradually building up in complexity and length: The first one in Magellan Strait was designed to get a first test of the launch- and recovery methods, a number of shorter ones in the Amundsen Sea were done to get the buoyancy adjusted and optimize the settings for the acoustic sensors. Three of the missions were focused mainly on science outcome, and designed to obtain fine-scale bathymetric data of glaciologically interesting areas as well as oceanographic surveys in key regions. A number of different survey patterns for oceanographic sampling were also attempted and evaluated. In connection with the AUV missions we also conducted autonomous aerial surveys to document the ice conditions.

4.7 Seal tagging activities

Lars Boehme

4.7.1 Background and objectives

The seal tagging activities on this cruise are part of the ITGC TARSAN project to observe ocean properties on the Amundsen Sea shelf especially of the winter months as well as delivering behavioral data of two top predators in this area. The intention on this cruise was to deploy up to 16 CTD-Satellite Relay Data Loggers (CTD-SRDL) made by the SMRU Instrumentation Group at the University of St Andrews on Southern Elephant seals (SES) and Weddell seals (WES) and anticipate that the seals will spend the winter in the study region. Both species moult in late summer and the aim was to catch seals at the end of their annual moult, so that the CTD-SRDLs stay attached to the seal until their next moult. Their dives will provide profiles of temperature and salinity, which will be transmitted back in near real time by satellite communications. These two species are chosen because they make relatively deep dives, usually to the sea bed, and remain in the region over winter. The spatial and temporal resolution of this dataset will enable us to

investigate the different roles of surface atmospheric and ocean advective fluxes in modifying the waters on the continental shelf before entering the ice-shelf cavities.

The objective was to tag as many Southern Elephant seals as possible, but nearly all SES encountered were still moulting, so that the deployment of CTD-SRDLs did not seem useful, as the CTD-SRDLs would come off within days. The moult of the Weddell seals was expected to be still on at the beginning of the cruise, but thought to be finished closer to the end. However, all WES caught were still in the middle of their moult or close to the end. Therefore, a deployment of a CTD-SRDL was often not done. A total of 2 SES and 17 WES were caught. CTD-SRDLs were deployed on 1 SES and 11 WES, while the others were still moulting on the head (see Appendix A9). The work was approved by the ethical committee of the University of St Andrews, UK and got the permit No29/2018 for activities under Section 7 of the Antarctic Act 1994 to conduct this specialist activity in Antarctica by the UK Foreign & Commonwealth Office.

4.7.2 CTD-SRDL deployments

Edward Islands – 10 and 11 February 2019

Two islands with haul-out sites for SES were known and visited by the seal team. The first one, on island 4 (Fig. 17; 73° 52.15'S / 102° 58.37'W) did contain several male SES that were still moulting and not ready to be tagged. The team proceeded to island 2 (Fig. 17) and found several male and female SES (73° 52.40'S / 102° 59.33'W). Two female SES at their end of the moult disappeared quickly into the water when the small boat arrived. Two females ready to be tagged stayed in the group of 10 seals total. The first one was darted, but two large male SES could not be stopped to approach and made a deployment of a CTD-SRDL impossible. The second female was separated from the group and tagged successfully with a CTD-SRDL (#14863). No other SES or WES at the end or after their annual moult were found.

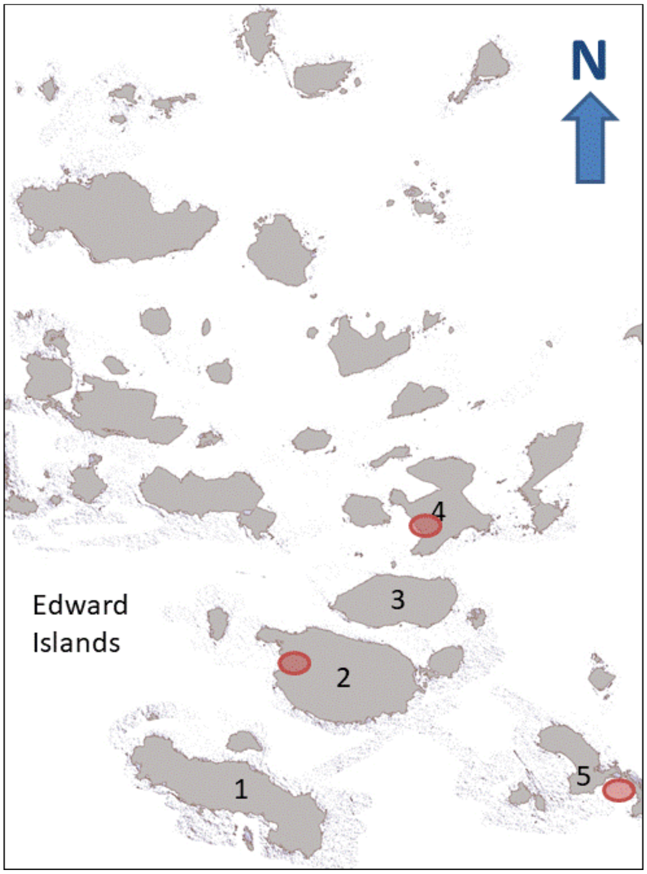


Figure 17. Sketch of the Edward Islands. Southern Elephant seal moulting sites indicated by red circles.

Schaefer Islands – 11 and 12 February 2019

No seal tagging was done previously on the Schaefer Islands, so that the seal team had to scout for possible SES haul-out sites. A beach with two moulting SES and two WES was found on the Schaefer Islands on February 11th (A in figure 18; 73° 39.06'S / 103° 12.86'W), but any attempt to catch seals had to be stopped due to high winds and a recall of all small boats by the captain. On the following day, the seal team went back to the same location and found one SES and three WES at that location. The SES was still moulting. All three WES were captured. One WES was still moulting, but two of the WES were deemed to be at the end of their moult and tagged with CTD-SRDLs (#14867 and 14870). A second SES haul-out site was discovered (B in figure 18; 73° 39.51'S / 103° 13.30'W), but a landing was not possible close to the beach. Therefore, a better landing was used (C in figure 18; 73° 39.41'S / 103° 13.71'W) and the seals approached from the

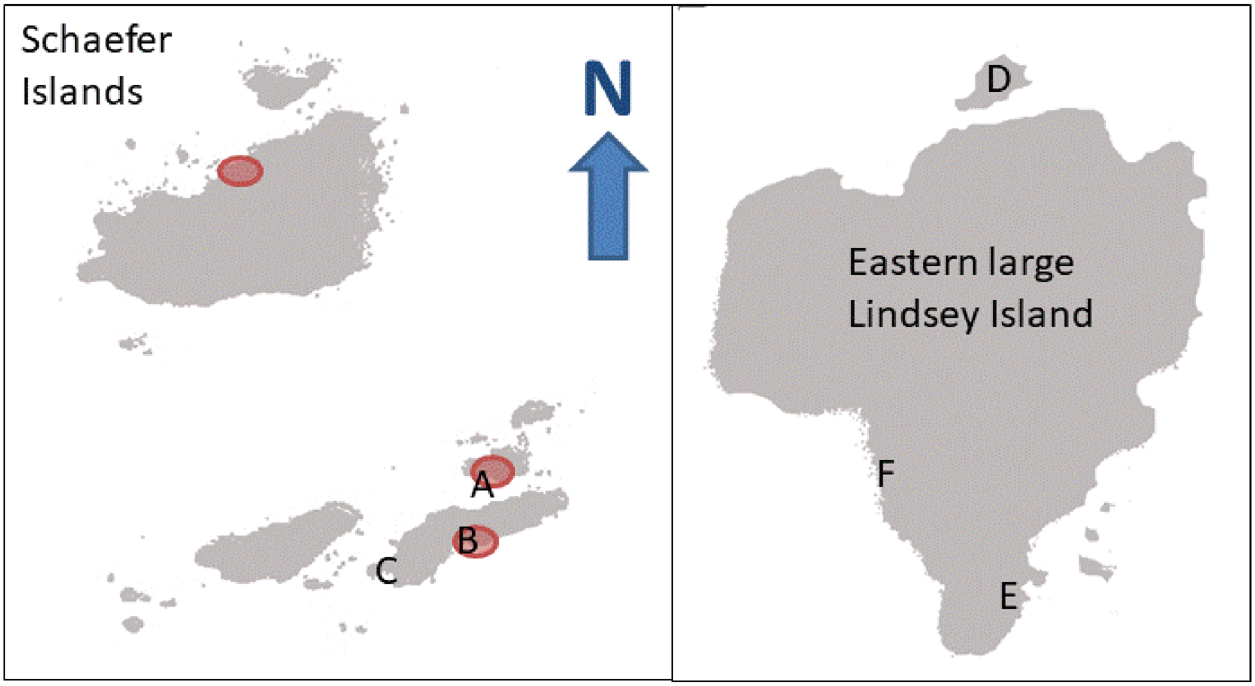


Figure 18. Sketch of the Schaefer (left) and Lindsey (right) Islands. Southern Elephant seal moulting sites indicated by red circles.

land side. However, the 10 male and one female SES were all in the middle of their moult and no CTD-SRDLs were deployed. Another single moulting SES was reported on the large northern island.

Lindsey Islands - 13 February 2019

No seal tagging was done previously on these Islands and small boats were deployed between the two large Lindsey Islands. A route was chosen to drive clockwise around the eastern large island as satellite images suggested a small island with a potential SES haul-out site to the north of it (D in figure 18). The island did provide a good beach for elephant seals to haul-out, but no SES were found, possibly due to its exposed location. The team scouted further and found an ice covered beach (E in figure 18; 73° 36.61'S / 103° 02.31'W) with several WES, but a landing was not possible due to a high ice edge at the beach, brash ice in front of the beach and a large swell. It was decided to continue and find a landing spot on the opposite site (F in figure 18; 73° 36.50'S / 103° 02.57'W) to approach the seals from the land side. Three adult and one sub-adult WES were found on the beach. Two adult seals were caught and one of them was at the end of the moult ready to be tagged with a CTD-SRDL (#14872).

Thwaites Eastern Ice Shelf - 4 March 2019

On March 4th ship-time was used to survey the shallow (less than 400m water depth) area to the northwest of the Thwaites Eastern Ice Shelf. Large icebergs and sea ice floes were intermixed. Several Crabeater seals were spotted and also some WES. When an individual WES was positively identified from the bridge using binoculars, a small boat was deployed and the ice floe approached. A total of 4 seals were captured and two were at the end of their moult and equipped with CTD-SRDLs (#14864 and #14894).

Edward Islands - 11 March 2019

When approaching the Edward Islands from the south, large numbers of WES and SES were spotted from the bridge on the islands and ice floes between the islands. A large number of WES were present (100+) potentially using the islands for hauling out after the fast ice in Cranton Bay broke off in the weeks before. The seal team started to work on island 5 (73° 52.57'S / 102° 57.35'W), but none of the elephant seals were moulted enough to be tagged. 4 WES were present on the beach as well. Three seals were caught and two were at the end of their moult and therefore tagged with CTD-SRDLs (#14897 and #14871). The seal team then moved to island 2 to check the known SES moulting site. Again, none of the elephant seals present there were at the end of their moult. A Weddell seal equipped with CTD-SRDL #14872, previously tagged on the Lindsey Islands, was present on the beach. The seal team then used the small boat to investigate the ice floes to the north of island 1, which were used by many WES. An ice floe with a single WES was chosen for tagging for ease of handling and equipped with CTD-SRDL #14891 (73° 52.59'S / 102° 59.94'W). During this process the catching bag made out of canvas was ripped so that it was decided to continue catching seals on land to support the use of darts. The known SES moulting site on island 4 contained 60+ male elephant seals, but none at the end of the moult. Two WES were present and one deemed suitable of tagging (#14869). The canvas bag was repaired and the northern beach of island 4 explored. Several WES were found on thick fast ice attached to the northwestern corner of the island. Three seals were caught and two more CTD-SRDLs deployed (#14868 and #14898).

4.8 GHC – Relative Sea Level work

Scott Braddock and Meghan Spoth

4.8.1 Goals for GHC

The goal of the GHC team for the 2018/19 season is to construct a relative sea-level (RSL) curve for Pine Island Bay (PIB) that will afford insight into late-Holocene (past several thousand years) thinning of ice in the region. We targeted raised beaches at different elevations for sampling to collect material suitable for radiocarbon dating to create a history of RSL. Our priorities for sampling were A) Organic material (Adelie penguin and seal remains, algae, shells), B) rock samples suitable for cosmogenic exposure surface age dating from above (if possible) or below the marine limit, and C) beach cobbles for optically stimulated luminescence (OSL) dating. Locating potential islands with raised beaches was done before the cruise with a total of eight islands identified in the PIB region from satellite imagery. We successfully explored and sampled from five of these islands in three different island chains (Fig. 19; Edwards Islands, Schaefer Islands, Lindsey Islands) over four field days.

4.8.2 Field work

Teams of four to five people, consisting of members from GHC, THOR and the NSF Writer in Residence, were transported to the islands by zodiac and left to carry out field work for the day. We arrived first at Edwards Islands (Fig. 20A) where we discovered that most islands were inaccessible because Adelie penguins occupied them in great enough density that we could not perform our work on raised beaches. Fortunately, one of the smaller islands hosted fewer penguins but still had raised beaches to sample. We landed at Edwards Island 1 (73° 52.6674'S, 102° 59.6928'W) on 10 February, 2019 and collected 49 organic samples from several raised beaches. Beaches ranged in elevation from roughly 3 m to 8 m. Almost the entirety of the island was covered in raised beaches other than several outcrops. No samples were collected for OSL or cosmogenic dating. An isolation basin was identified on this island that may prove worthwhile to core on a future cruise to try and locate dateable material at the marine/freshwater transition as the island uplifted.

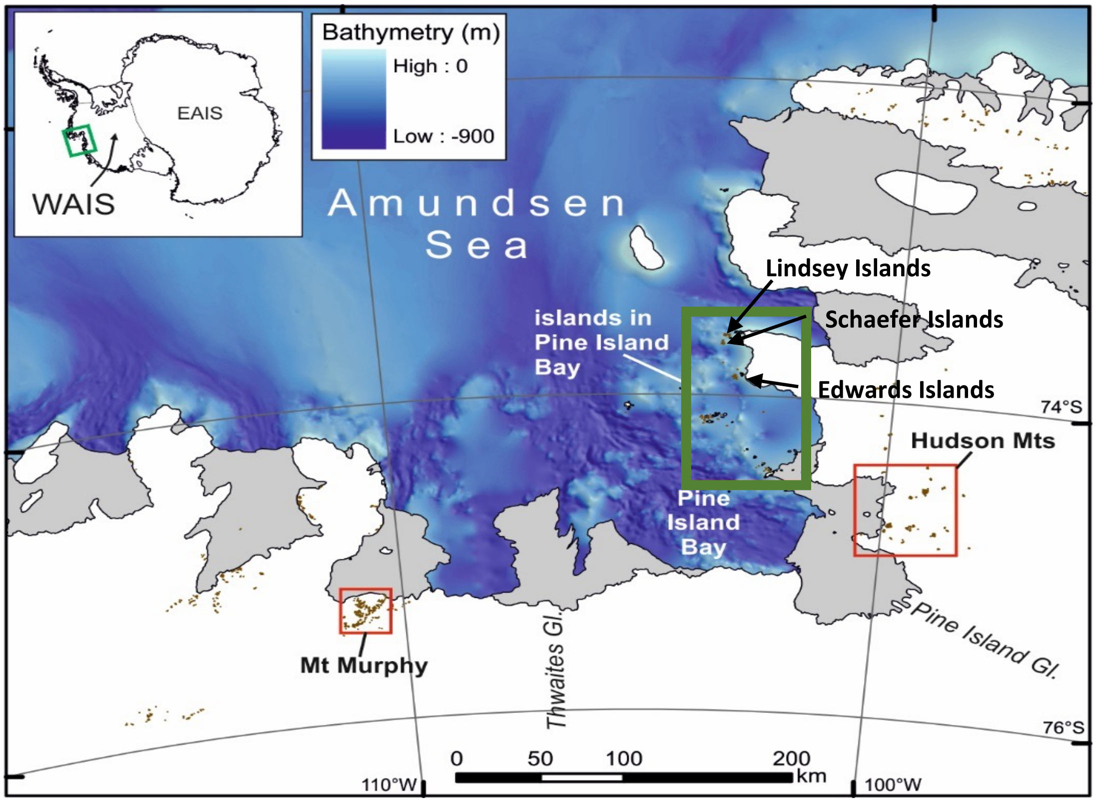


Figure 19. Map of GHC field area. Green box highlights location of sampled sites in the Lindsey, Schaefer and Edwards Islands. Red boxes highlight areas of interest for GHC studies to date past ice fluctuations in upcoming 2019/20 and 2020/21 field seasons.

Overnight the NBP then transited north to the Schaefer Islands (Fig. 20B). On 11 February, 2019 our team landed on Schaefer 1 (73° 38.4648'S, 103° 13.3422'W). However, due to inclement weather, we returned to the NBP before any samples were collected. Before leaving on the zodiac, we were able to scout the island and saw evidence of marine sediments. The following day, 12 February, 2019, calmer seas allowed us the day to sample on Schaefer 1. We found several beaches covering a range of elevations from 3 m to several around 15 m above sea level and collected a total of 74 organic samples. Further work is required on this island to properly sample beaches at higher elevations as well as collect bedrock samples for cosmogenic dating.

The following morning the NBP transited a short distance north to the Lindsey Islands (Fig. 20B). On 13 February, 2019, we landed on Lindsey 1 (73° 36.3726'S, 103° 2.5578'W) where we found a well-preserved, continuous set of beaches covering nearly the full elevation of the island. However, beaches were only well exposed between 15 m and 26 m asl. Beaches below 15 m were

covered by a thick snow/ice pack. A few of the beaches around 15 m appeared to have recently melted out from this snow/ice. 73 organic samples were collected as well as two rock samples from a glacially-polished, granitic bedrock outcrop. The latter two samples will be analyzed for cosmogenic surface exposure ages.

On 12 March, 2019 we returned to the Edwards Islands for an additional day of work as we accompanied the seal tagging team. A fresh snow covered many of the beaches we had identified in satellite imagery, however enough surface remained exposed to identify raised beaches on two islands. On Edwards 2 (73° 52.478'S, 102° 59.070'W) we collected 36 organic samples and two bedrock samples for cosmogenic surface exposure dating on beaches ranging from 3 m to 11 m asl. At the highest elevation on the island, 21 m, there was evidence of marine sediments as well so several organic samples were collected at this elevation. On Edwards 3 (73° 51.914'S, 103° 0.825'W) we sampled an additional 48 organic samples from raised beaches ranging from 3 m to 6 m asl. Beaches lower than 3 m were covered by snow/ice and not possible to sample.

In total, we collected nearly 300 organic samples from the five islands and four rock samples for cosmogenic dating on two of the islands. All samples for cosmogenic dating were collected from bedrock below the marine limit. For all five of the islands visited, marine sediments were evident from sea level to the highest elevations. Most beaches consisted of angular to subangular, coarse sediments (roughly 10-30 cm in diameter). None of the islands contained beaches suitable for collecting samples for OSL dating.

4.8.3 Future work

This will be the only field season to collect samples from the islands to construct an RSL curve for PIB. Samples will be shipped to the University of Maine and prepared for radiocarbon dating over the summer, 2019. GHC will return to the Hudson Mountains and Mt. Murphy (Fig. 19) in 2019/20 and 2020/21 to complete field work to drill for sub-glacial bedrock samples that will be dated using the cosmogenic exposure age method. Results from the constructed RSL curve for PIB will be used in conjunction with dated subglacial bedrock samples to better understand late Holocene ice fluctuations of Thwaites and Pine Island Glaciers.

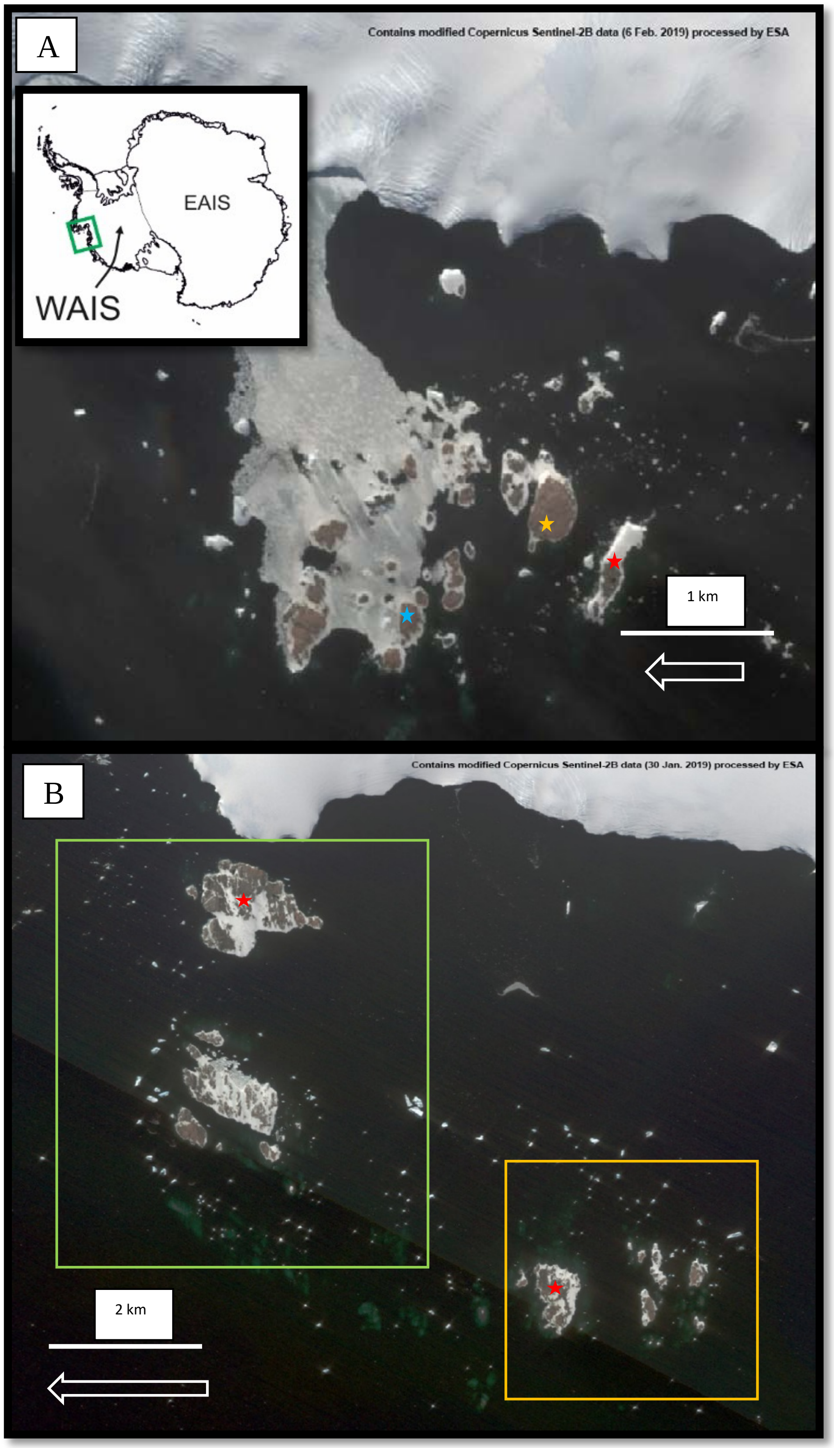


Figure 20. A) Edwards Islands. From right to left, red star indicates Edwards 1, yellow star Edwards 2 and blue star Edwards 3. B) Green box highlights Lindsey Islands with red star indicating Lindsey 1. Yellow box highlights Schaefer Islands with red star indicating Schaefer 1.

4.9 Mooring Operations

Mark Barham

4.9.1. Background and objectives

The five BAS moorings (Fig. 21) form part of the BAS contribution to ITGC and were deployed using NERC National Capability funding through the Ocean Forcing of Ice-Sheet Change (OFIC) project. Four moorings were recovered and redeployed during cruise ANA06B on board IBRV *Araon* in 2016. However, the fifth, mid-shelf mooring, was inaccessible due to a large area of 98% sea ice cover.

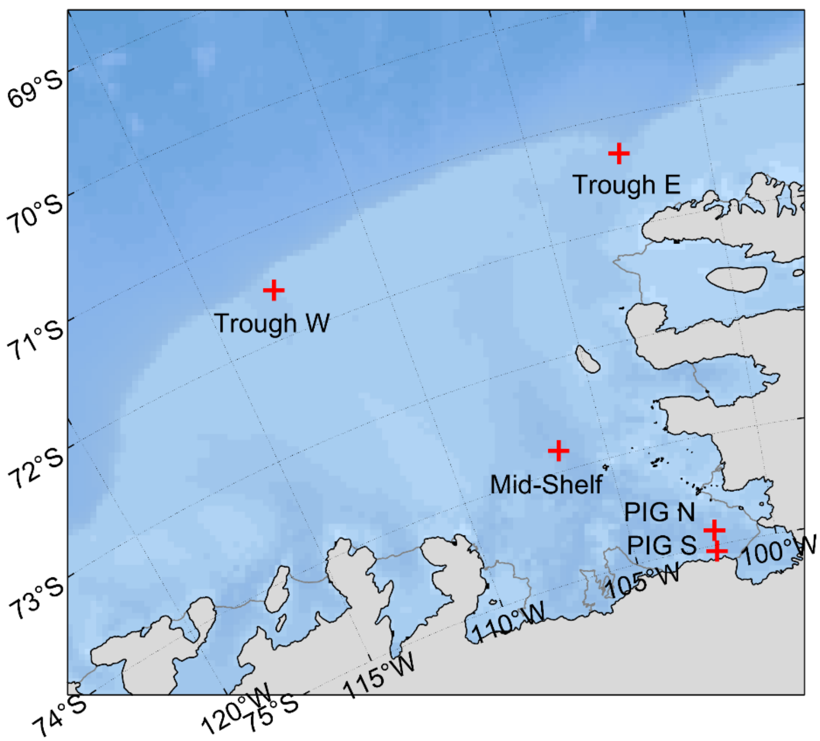


Figure 21. Locations of BAS moorings in the Amundsen Sea.

Our intention during NBP19-02 was to recover and redeploy as many of the five BAS moorings as could reasonably be achieved given weather and time allocation. Having not been recovered since its initial deployment in 2014, the mid-shelf mooring was given the highest priority for

recovery. PIG_S and PIG_N moorings were to be recovered in preference to both Trough_E and Trough_W moorings.

The planned vessel transit into the eastern Amundsen Sea passed close to the Trough_E mooring. However, heavy ice thwarted any opportunity for a recovery and the decision was made to route the vessel through lighter ice conditions. The mid-shelf mooring was successfully recovered 8 days before the 5th anniversary of its 2014 deployment. Redeployment was completed the next day. The mooring at PIG_N was successfully released, but during recovery a section of the mooring became entangled with the starboard propeller which resulted in dissecting the mooring in two. Both sections were recovered, but 5 instruments had been lost. Fortunes did not improve on arrival at PIG_S. Despite numerous attempts to communicate with both releases, followed by extensive passes over the site with various survey equipment, the mooring was deemed to have been moved beyond the range of the transponder. A slightly modified version of the PIG_S mooring was redeployed using elements from PIG_N and any available spares. Nothing was redeployed at PIG_N.

4.9.2 Mid-shelf recovery and redeployment

The recovery and redeployment of the mid-shelf mooring were safely completed on the 14th February 2019, without any noteworthy events. Only the two microcats were still logging at the time of recovery. All other instrumentation had stopped either as a result of battery depletion or full memory. However, the uppermost Aqualogger on the mooring stopped much earlier than expected, acquiring just under 5 months of data. The redeployed mooring landed 89 m from the intended target but also 70 m deeper than planned.

4.9.3 PIG_N recovery

On the 7th March 2019, recovery of the PIG_N mooring began as any other, successfully ranging and firing one of the IXSEA acoustic releases with the floatation appearing on the surface within a few minutes. On approach to the mooring, the syntactic buoyancy (containing the acoustic Doppler current profiler) was brought down the side of the vessel. As attempts were being made to grapple the floatation, it slipped below the surface and became entangled in the starboard propeller together with mooring line that had originally been above the floatation. This resulted in

the mooring being split into two sections; a ~200 m section ending just below the 5 m string of glass spheres, and a shorter ~7 m section containing the 3 m string of glass spheres and the acoustic releases. Equipment and instrumentation between these two sections, including the ADCP, a SBE Microcat and 3 Aqualogger thermistors, were unfortunately lost.

We were quickly able to grapple and secure the longer of the two mooring sections and placed a MOB marker on the position of the second section. Recovery of the longer section progressed without further incident. Once this had been recovered, the vessel retraced its track and located the shorter mooring section. This was brought alongside and safely recovered to deck.

4.9.4 PIG_S recovery

Later, on the 7th March 2019, the vessel arrived at PIG_S where attempts were made to establish communication with the releases. After a number of attempts we reverted to running lines over the site utilising the EM122 MBES and EK 60 fish finder at both 38kHz and 120kHz (Fig. 22). Neither of these systems returned anything that might have resembled the PIG_S mooring. Efforts to locate the mooring were abandoned 3 hours later.

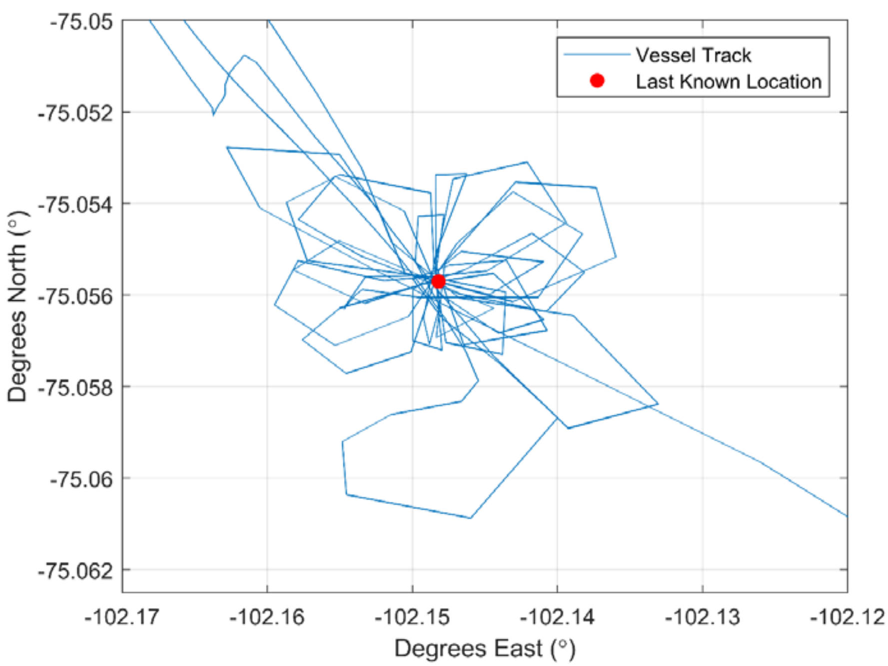


Figure 22. Survey lines of MBES and EK60 in an effort to find the PIG_S mooring.

4.9.5 PIG_S deployment

With a partial mooring recovered from PIG_N and nothing recovered from PIG_S, the decision was made to deploy a slightly modified version of the PIG_S mooring at PIG_S. A Nortek Aquadopp DW (3000m), SBE Microcat and RBR concerto3 CTD were deployed in place of the ADCP at a target depth of 377 m.

Notes from a previous deployment suggested a minor shift in the deployment position, slightly north or the last target, in an attempt to land the mooring in the desired water depth. With the aid of recently acquired bathymetry, the target mooring position was moved to a point that we anticipated would achieve the desired depth.

The deck and mooring were configured for an anchor last deployment and the *Palmer* made a slow approach to the drop point from a position approximately 1 nm downwind. The deployment progressed smoothly, and save for a minor reconfiguration of the spooled mooring rope, it was completed without incident. Following deployment, 4 triangulation points were taken to verify mooring position. In this case the mooring ended up deeper than planned, coming to rest in 841 m, instead of the targeted 810 m. Operations were completed on the 9th March 2019.

4.9.6 Extended PIG_S mooring search

Following deployment of the modified PIG_S mooring, an extended search for the original missing PIG_S mooring was conducted (Fig. 23). In both July 2014 and 2015, icebergs had moved the PIG_S mooring from its original deployed position in a westerly direction. While we were unable to communicate with either release from the original deployed position, we assumed the mooring had suffered a similar fate and so progressed in a westerly direction, stopping every 2 nm to try and re-establish communication with the releases. This search was conducted for 4 hours before being called off.

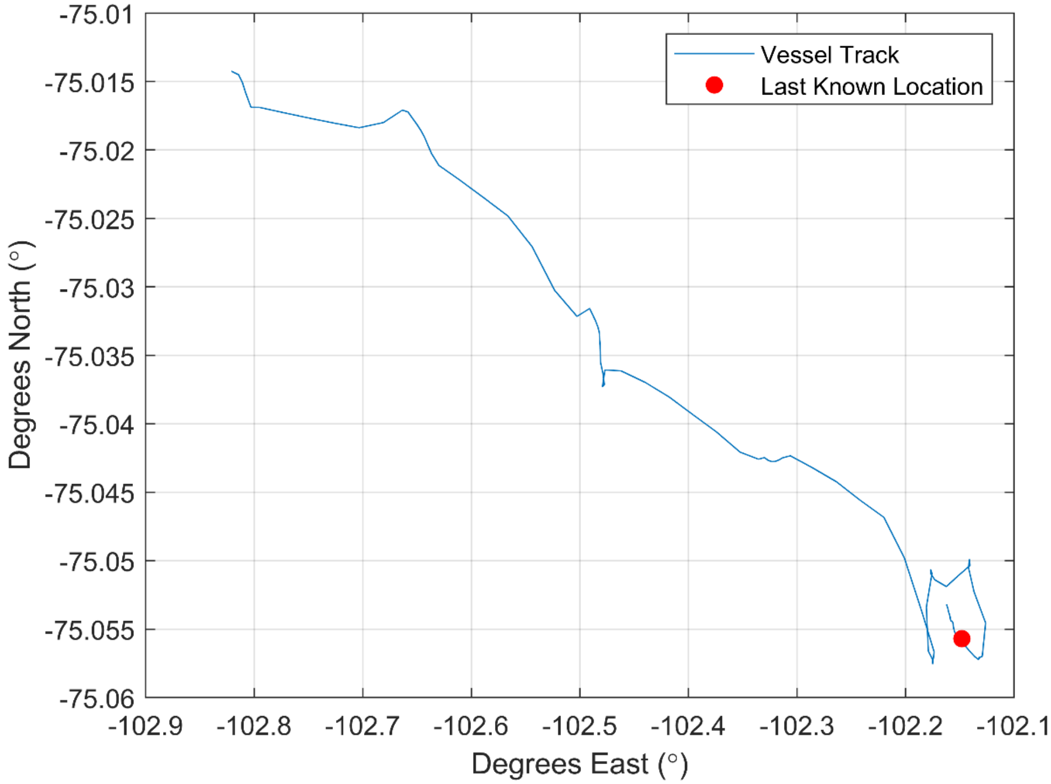


Figure 23. Vessel track undertaken while searching further west for the PIG_S mooring.

4.10 Sea ice observations

Aleksandra Mazur

Sea ice observation were carried out by Aleksandra Mazur, Yixi Zheng, Peter Sheehan and Salar Karam between February 6th and March 17th 2019. There were 372 observations made, between 5-24 observation per day in both the Amundsen Sea and the Bellingshausen Sea (Fig. 24), following the protocol set out by the SCAR Antarctic Sea Ice Processes and Climate (ASPeCt; https://data.aad.gov.au/aspect/) initiative.

The sea ice concentration varied from 0 to 100%. In general, almost no ice was observed north of 70˚S. The highest sea ice concentrations were observed in the region north of the Pine Island Bay. The Thwaites and Pine Island polynya were almost free of sea ice. Similarly, the area in front of the Cosgrove Ice Shelf.

The sea ice that was observed were mostly first year sea ice floes with the size of few to few dozen meters. In the end of the cruise grease ice and new ice also started to form (see attached excel sheet).

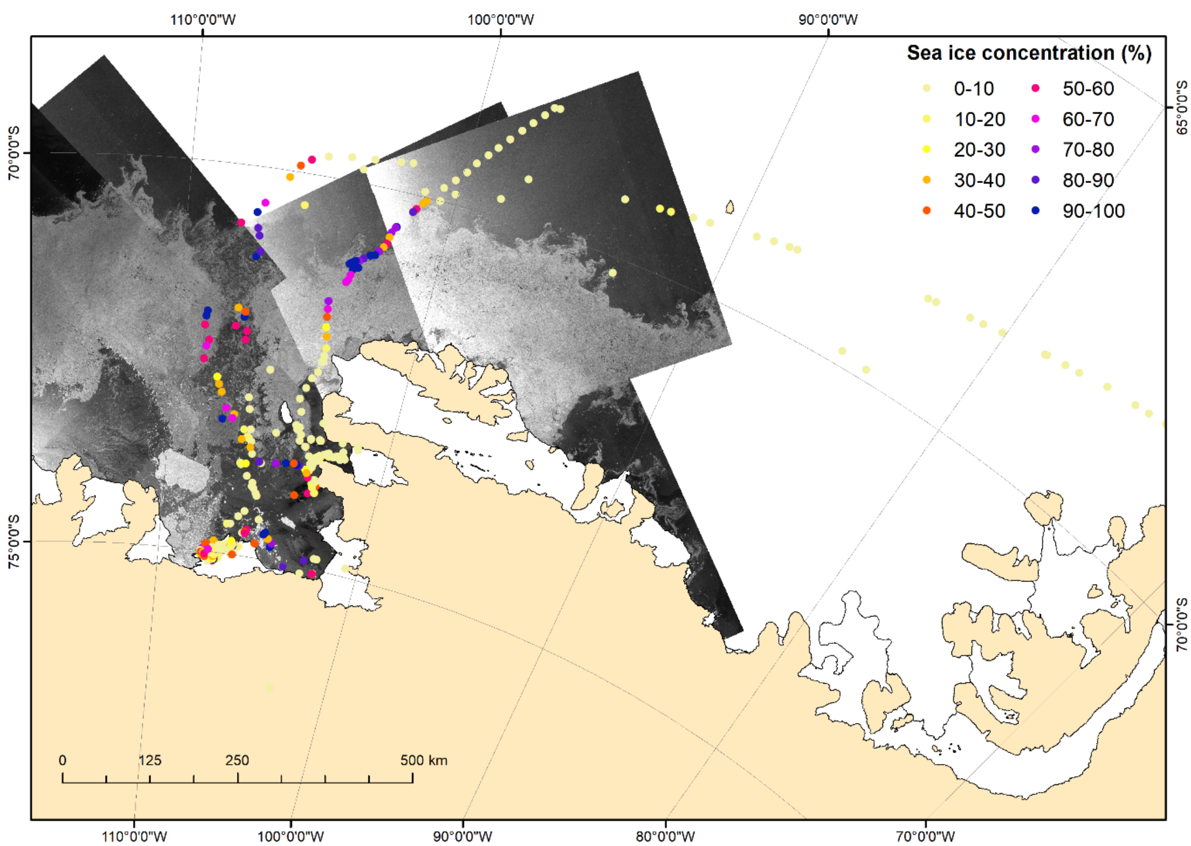


Figure 24. Sea ice concentration in the Amundsen Sea and the Bellingshausen Sea between February 6th and March 17th 2019. Background images are Sentinel-1 SAR images taken acquired between March 7th-10th 2019.

4.11 Media and Outreach

Tasha Snow

One of the key goals of the individual International Thwaites Glacier Collaboration projects and the collaboration as a whole is to maximize the broader impacts of the research being conducted, both through media engagement and outreach. The Science Coordination Office within ITGC and NSF/NERC helped to bring together a media team onboard NBP19-02 to achieve that goal. The media team included five individuals. NSF/NERC invited applications for journalists to come onboard NBP19-02 and two environmental journalists were chosen, both respected for their coverage of climate change and Antarctic research. Through the NSF's rigorous Antarctic Artists and Writers Program process, a writer was also selected to join the research cruise. As a part of THOR's broader impact proposal, an outreach representative for their team came onboard to write blogs and produce photo and video content. The SCO sent a media facilitator to coordinate and help facilitate media interactions with the scientists, blog, and capture media content. Together the media team achieved unprecedented media coverage and outreach for NBP19-02 and the ITGC. The media presence brought coverage that outpaced typical outreach efforts by three to four orders of magnitude, demonstrating the exceptional value of having a media presence for science.

4.11.1 Media coverage

The cruise included two journalists: Jeff Goodell from Rolling Stone Magazine and Carolyn Beeler from Public Radio International's (PRI) "The World". Elizabeth Rush Mueller, creative non-fiction writer, also participated on this cruise through the NSF's Antarctic Artists and Writers Program. The media team onboard conducted over 330 interviews over the course of eight weeks. Fifteen articles were published in Rolling Stone Magazine, ten radio reports were produced for "The World", a non-narrative for "The World", seven interviews were conducted with Boston Public Radio, one interview with BBC World Service "Science in action," two articles were published with National Geographic, and one article was written for American Scholar (Table 3). After the cruise, a long-piece "special" article and short video will be created for Rolling Stone magazine, 6 long radio segments for "The World," and a published book.

One of the primary goals for the ITGC Science Coordination Office is to amplify the impact of the research being conducted within all of the ITGC projects, through enhanced data sharing and wider media coverage. This cruise has received unprecedented media coverage, which has spurred the interest of the public and scientific programs in other countries. Viewership for each of the media products released as a result of this research cruise include:

Carolyn Beeler’s reports air in "The World" from PRI/PRX, the BBC World Service and WGBH in Boston, which has more than 3 million weekly listeners and airs on 322 public radio stations in the US and Canada. The website, where brief online versions of each of her stories on “The World” are posted, averages 1.4 million visits a month. Each of those stories also reach an additional audience through social media posts in, for example, the Instagram Stories that accompany most of Ms. Beeler’s dispatches. Some of her work also airs on Boston Public Radio (210,000 weekly listeners in the Boston area) and the BBC's "Science in Action," which airs several times a week on the BBC World Service English service (no listenership statistics for the show, but BBC English has ~70 million weekly listeners).

Jeff Goodell’s articles appear in Rolling Stone Magazine. Rolling Stone has a 650,000 magazine circulation. The average magazine issue reaches ~3 million readers and the website has 25-30 million readers a month.

Elizabeth Rush's writing on the journey has appeared in National Geographic (circulation: 6,500,000). Upon return she will publish a non-fiction book featuring the cruise with Milkweed Editions, one of the most vibrant independent literary publishing houses in the country. Initial anticipated print run is 10,000 copies hardcover and 10,000 copies soft cover. Additionally Elizabeth Rush’s work regularly appears in a variety of literary and news outlets including The New York Times (circulation: 2,600,000), Harpers Magazine (circulation: 125,000), Orion Magazine (circulation: 25,000), and Le Monde Diplomatique (circulation: 125,000) amongst others. Upon returning from Antarctica, Rush will design and teach a new Advanced Creative Nonfiction Writing Workshop at Brown University inspired by her time aboard the RVIB *Nathaniel B. Palmer* that helps students develop the skills necessary to communicating science to a broader public. It will be modeled on the immersive writing practice Elizabeth Rush Mueller will employ while participating in the Antarctica Artists and Writers Program.

4.11.2 Outreach

Outreach was achieved through blogging, social media, and work with students/community groups. 11 blogs were created for the ITGC website by Tasha Snow and 12 for the THOR website by Linda Welzenbach. Both blogs covered topics ranging from ship life to each part of the scientific work conducted for NBP19-02. Social media, primarily Twitter, was used to help broaden communication, fill in gaps between larger media products, and draw viewership to the websites. The blog websites received heavy traffic for NBP19-02. The ITGC blog received 32,342 total pages viewed, 11,964 unique visitors, and 14,403 unique sessions. Of the acquisitions, 37.5% were direct, 34% referral (Ranking by referral: 1-nbcnews.com, 2-jpl.nasa.gov, 3-yahoo.com, 4-foxnews.com, 5-nasa.gov, 6-washingtonpost.com), 23.5%

through organic search, and 5% from social media (1- Facebook, 2- Twitter, 3- Google+). The THOR blog received 2605 total page views, 1317 total visits, and 1054 unique visitors.

Outreach also included educational work where ship participants answered questions for various K-12 classes and a Girl Scout troop in Alabama and Maine, provided class visits and 360 video content for the University of Maine "Follow a Researcher" program, and gathered imagery and 360 video content to create a live talk for University of Colorado Boulder's Fiske Planetarium "Climate Change in our Backyard" program. Onboard the ship, PI's answered questions about the NBP19-02 research and life onboard the ship during calls to the University of Alabama Evolutionary Studies Club for Darwin's birthday and to Environmental Chemistry class at Cleveland State University. The latter arose when the professor for the class was inspired to contact our chief scientist by one of Ms. Beeler's radio reports on "The World." An interview was also conducted with a Swedish Radio station.

4.11.3 Photo and video content collected

This cruise accumulated over 8500 pictures and videos, including one hour of drone footage, one hour of GoPro time-lapse, three hours of 360 video footage, and two hours of professional quality video. Many of the photos have been used by the media team onboard in their reports and articles, and some of the video has been slated for use by Silverback Films – who created Frozen Planet and Planet Earth – in their upcoming BBC One prime time (UK) and BBC worldwide (Discovery Channel USA) natural history landmark series called *The Perfect Planet*. The photos and video will also be available for production of an ITGC promotional video, and for future use by the media in their articles, video, and book.

Table 3. Media publications during NBP19-02.

Date	Type	Venue	Topic
Jeff Goodell			
1/30/2019	Online article	Rolling Stone magazine	Jeff Goodell begins his trip to Thwaites Glacier
	https://www.rollingstone.com/politics/politics-features/jeff-goodell-journey-to-antarctica-dispatch-1-786538/		
2/4/2019	Online article	Rolling Stone	How we will see deep beneath the ice
	https://www.rollingstone.com/politics/politics-features/hugin-antarctica-789613/		

2/6/2019	Online article	Rolling Stone	Navigating the wildest waves in the Southern Ocean
	https://www.rollingstone.com/politics/politics-features/antarctica-drake-passage-791952/		
2/8/2019	Online article	Rolling Stone	How I survived Drake Passage
	https://www.rollingstone.com/politics/politics-features/drake-passage-waves-790748/		
2/14/2019	Online article	Rolling Stone	How scientists are using seals to measure the warming ocean
	https://www.rollingstone.com/politics/politics-features/antarctica-seal-tagging-794759/		
2/19/2019	Online article	Rolling Stone	An emergency at sea
	https://www.rollingstone.com/politics/politics-features/antarctica-climate-change-thwaites-glacier-796442		
2/22/2019	Online article	Rolling Stone	When the best laid plans go awry
	https://www.rollingstone.com/politics/politics-features/antarctica-emergency-798753/		
2/25/2019	Online article	Rolling Stone	Reckoning with uncertainty
	https://www.rollingstone.com/politics/politics-features/antarctica-melting-speed-800099/		
3/1/2019	Online article	Rolling Stone	Face-to-face with the doomsday glacier
	https://www.rollingstone.com/politics/politics-features/antarctica-thwaites-doomsday-glacier-goodell-801622/		
3/6/2019	Online article	Rolling Stone	Mapping Thwaites
	https://www.rollingstone.com/politics/politics-features/journey-to-antarctica-mapping-thwaites-goodell-803526/		
3/8/2019	Online article	Rolling Stone	Ping pong smack down/life on ship
	https://www.rollingstone.com/politics/politics-news/journey-to-antarctica-goodell-ping-pong-805188/		
3/12/2019	Online article	Rolling Stone	The dark art of coring
	https://www.rollingstone.com/politics/politics-features/journey-to-antarctica-coring-thwaites-glacier-sea-pig-806769/		
3/14/2019	Online article	Rolling Stone	What scientists think of Trump's latest climate tweet

	https://www.rollingstone.com/politics/politics-features/trump-climate-change-tweet-808208/		
3/20/2019	Online article	Rolling Stone	Is this what a climate catastrophe looks like in real time
	https://www.rollingstone.com/politics/politics-features/journey-to-antarctica-is-this-what-a-climate-catastrophe-looks-like-in-real-time-810392		
3/25/2019	Online article	Rolling Stone	Cruise wrap-up

Carolyn Beeler			
2/1/2019	Radio report	The World	Gearing up and shipping out
	https://www.pri.org/stories/2019-02-01/dispatch-1-gearing-and-shipping-out		
2/11/2019	Radio report	The World	Crossing the Drake Passage
	https://player.fm/series/the-world-science-tech-environment-1340006/dispatch-2-crossing -the-drake-passage		
2/15/2019	Radio report	The World	Iceberg sighting
	https://www.pri.org/stories/2019-02-15/dispatch-3-ships-first-encounter-icebergs		
2/18/2019	Interview	The World	Field work begins, cue the seals
	https://www.pri.org/stories/2019-02-18/antarctica-dispatch-4-fieldwork-begins-then-stops		
2/26/2019	Radio report	The World	Detour, with scenery
	https://www.pri.org/stories/2019-02-27/antarctica-dispatch-5-detour-scenery		
2/28/2019	Interview	The World	First sight of Thwaites
	https://www.pri.org/stories/2019-02-28/antarctica-dispatch-6-first-sight-thwaites-mapping-uncharted-seafloor/		
3/6/2019	Radio report	The World	Under Thwaites Glacier
	https://www.pri.org/stories/2019-03-06/antarctica-dispatch-7-under-thwaites-glacier		
3/13/2019	Radio report	The World	Behold grease, shuga, and pancake ice
	https://www.wesa.fm/post/antarctica-dispatch-8-behold-grease-shuga-and-pancake-ice		
3/19/2019	Radio report	The World	Coping with climate change - a scientist's perspective

3/25/2019	Radio report	The World	Getting back to port, what's next with the science
2/13/2019	Interview	Boston Public Radio (BPR)	Science update
	https://www.wgbh.org/news/local-news/2019/02/13/bpr-full-show-02-13-19		
2/26/2019	Interview	BPR	Science update
3/6/2019	Interview	BPR	Science update
3/13/2019	Interview	BPR	Science update
3/19/2019	Interview	BPR	Science update
3/21/2019	Interview	BBC World Service "Science in Action"	Science update

Elizabeth Rush

3/7/2019	Online article	National Geographic	These women are changing the landscape of Antarctic research
	https://www.nationalgeographic.com/environment/2019/03/women-scientists-of-international-thwaites-glacier-collaboration-antarctica/		
3/12/2019	Online article	National Geographic	Here's what Antarctica's calving glaciers look like up close
	https://www.nationalgeographic.com/environment/2019/03/watching-thwaites-glacier-calving-antarctica		
Summer 2019	Magazine article	American Scholar	Future of Antarctica in 5 questions

5 List of Scientific Equipment Used

5.1 Echo sounders

Kongsberg Simrad EM122 multibeam echo sounder

Knudsen Chirp 3260 acoustic sub-bottom profiler

Kongsberg Simrad EK60 echo sounder with 38, 120 and 200 kHz Tx frequencies

Benthos DS-7000 acoustic transponder

5.2 Oceanographic instruments

Sea-Bird Conductivity-Temperature-Depth (CTD) system with 24-bottle (12L) rosette, also including oxygen sensor, fluorometer, transmissometer, PAR sensor and altimeter

Teledyne RDI Ocean Surveyor 38 kHz Acoustic Doppler Current Profiler

Teledyne RDI Ocean Surveyor 75 kHz Acoustic Doppler Current Profiler

Intruments measuring uncontaminated seawater pumped from beneath the hull, including thermosalinograph, fluorometer, and intake thermometer

Meteorological instruments including: air temperature thermometer, anemometer, barometer, humidity sensor, PAR sensor and UV sensor

5.3 Winches and wires

150 HP Markee winch with DUSH 9-11 9/16" 3x19 wire for coring over stern

75 HP Markee winch ('lower waterfall') with DUSH 5-5 5/16" wire for starboard coring

Markee electromechanical winch (Baltic Room) with Rocheter DUSH 5 0.322" hydrographic wire for CTDs

5.4 Coring equipment

Jumbo coring system configured as 20 ft (~6 m) gravity corer and deployed over the stern

Kasten corer (150 mm square section) with 3 m and 1.5 m barrels and deployed over the stern

OSIL megacorer (old and new models), deployed from starboard A-frame

Ocean Instruments Inc. BX-650 giant box corer (500 mm square box) deployed from starboard A-frame

5.5 Potential Field Equipment

Bell BGM-3 shipborne gravity meter (S/N 210)

5.6 Navigation

Seatex Seapath 200 and 320+ (switched between the two during the cruise)

Gyro

5.7 Data Logging

RVDAS system

5.8 Hugin AUV

EM2040 multibeam echo sounder

EdgeTech dual frequency (75 and 410 kHz) sidescan sonar

EdgeTech DW-216 sub-bottom profiler

Kongsberg MS1000 upward-looking sonar

Upward-looking ADCP

2 x Sea-Bird combination SBE-19plusV2 and SBE-43

Sea-Bird SUNA nitrate sensor

Sea-Bird/WetLabs ECO Triplet (FLBBCD) (fluorescence, chlorophyll and backscatter sensors)

Fluidion water sampler (14 x 150 cl bottles)

cNODE ultra-short baseline 12 kHz navigation transponders

5.9 Ocean Gliders

Kongsberg Seagliders (one from University of East Anglia, and one from Caltech recovered)

Seaglider SG620 was equipped with:

- standard flow through Seabird CT cell
- Aanderaa 4330F optode
- Wetlabs Ecopuck (Chlorophyll, OBS 700 and OBS 470)

6 Equipment operation and performance

6.1. EM122 multibeam echo-sounder performance

Ali Graham and Kelly Hogan

6.1.1 Description and operation

The EM122 is a hull-mounted high resolution (1 x 1˚ operating at 12 kHz) deep-water multibeam echo-sounder forming the principal sonar for bathymetric survey on the vessel. The echo sounder receives and processes data from several ancillary systems in order to locate depth measurements with accuracy. These include the ship's GPS positioning system, and the inertial (motion) reference unit (MRU), both of which are described in separate sections of this report.

Logging of EM122 data was initiated at 12:46 UTC on Julian Day 035 (4^{th} Feb 2019), after clearing the Chilean Exclusive Economic Zone limit, 200 nautical miles from the coastline. The system was operated at virtually all times when the vessel was in motion, until logging was stopped at 06:34 UTC on Julian Day 081 approaching the end of the cruise.

Unlike many other polar research vessels, the RV *Nathaniel B Palmer* does not operate a K-sync through which different acoustic systems are synchronized. As a result, during the majority of geophysical survey on NBP19-02 both the EM122 and 3.5 kHz Chirp sub-bottom profiler were operated independently with ping cycling determined internally by the two systems, respectively. This meant that on rare occasions the multibeam system locked on to interference generated by the Chirp profiler requiring the user to force the system back to tracking the sea floor (using Force Depth or by altering the maximum and minimum depth settings). Periodic interference was also observable as 'smiles' in the multibeam swath bathymetry, especially in deeper water survey.

During periods of ship activity, the width of the multibeam swath was set to a level appropriate for the water depth and weather conditions. Under favourable conditions, beam angles were set as wide as 70º, but were reduced if the outer beams became discordant or noisy, or if the EM122 had problems with bottom tracking. Typical beam angles for survey ranged between 60-65º athwartship. Minimum and maximum depths were set as appropriate for the regional or anticipated bathymetry. In shallower depths in particular it was necessary to fix the maximum depth close to

the actual water depth in order to stop the EM122 from picking spurious multiple sea-floor reflections.

The ping mode during survey was set automatically by SIS based on the sea-floor depths in the working area. In areas of moderately shallow (on-shelf) depth, the mode was set manually to MEDIUM or DEEP to avoid noticeable sector-boundary artefacts associated with across-track bottom-tracking switches from amplitude to phase (encountered in SHALLOW and VERY SHALLOW modes specifically).

The EM122 system also has the ability to operate in a dual ping mode with two pings in the water at once, increasing along-track resolution substantially. For our work at Thwaites Glacier, this extra resolution was essential to producing the finest grid possible of the ice-proximal sea bed. For the beginning part of the cruise, dual swath mode was set to 'DYNAMIC' (an internally controlled depth-calculated on/off switch). On 27th February 2019 (16:55Z), during work in the central Amundsen Sea, the dual ping mode was set to 'FIXED' in order to force the system to maintain along-track sampling even with frequent changes in sea floor elevation. This mode was retained for the remainder of the cruise activities.

Sound velocity profiles, derived from XBT casts and CTD deployments during the cruise, were acquired and applied in the SIS system to provide information on the water structure of the survey area that is critical for raytracing and accurate depth calculations. CTD casts are described in full in sections 4.4 and 6.5 of this report, and XBT procedures are described in section 6.10.

Alongside the acquisition of bathymetric data, during survey at and close to the margins of Thwaites and Pine Island Glaciers, the EM122 water-column data were also logged to capture information relevant to the ocean water masses and ice draft in the immediate vicinity of the ice-shelf edge. This function performed well without issue during periods in which the water-column logging was active.

6.1.2 Problems encountered

Overall, the EM122 performed well during cruise NBP19-02. SIS is the real-time operator interface and data processing system for the EM122. On other vessels equipped with Kongsberg sounders, SIS has been prone to semi-regular crashes that require restart and/or reboot of the systems (software and top-end hardware). One of these problems stems from an ongoing issue related to the 'GridEngine' module that exceeds memory capacity/swap space to build real-time gridded versions of the incoming multibeam data. On the *Palmer*, the SIS suffered repeated but infrequent crashes associated with 'GridEngine' failures (Table 4). Twice during the cruise, the operator machine also suffered crashes associated with complete loss of transmission that required a hard reset at the transducer box. Other crashes of the SIS terminal were attributable to errors with processes linked to the NVIDIA graphics card, or to the import of large background images to the 'Geographical' window display.

One other apparent failure stemmed from incorrect settings being applied in the SIS runtime parameters whereby the maximum depth was set shallower than the actual water depth. The result of this is an apparent loss of transmission and return. In future, users should ensure that maximum depth is not shallower than the true depth when faced with a pinging sounder but no returns (a check of the Knudsen Chirp profiler water depth can help in this regard).

A final observation made during survey is that the *Palmer* EM122 is sensitive to both sea state and ice conditions. Because the EM122 Tx array is mounted a significant way starboard of the ship centerline, substantial wind (>20 knots) to the beam or a swell hitting the vessel on the starboard size causes aeration of water beneath the array and attenuation of the signal at the source. Survey direction therefore has a significant effect on the quality and continuity of the incoming data, particularly in poor weather but occasionally even during relative moderate sea states. In addition, newly-forming sea ice (grease ice) tended to blank the transducer intermittently although these conditions were encountered very rarely on the expedition. Obtaining good quality acoustic data whilst breaking sea ice, as with any vessel, was an additional challenge. Lastly, the reported optimal survey speeds for multibeam acquisition on the *Palmer* of <3.7 and >9.3 knots are also supported by work on this cruise which provided anectodal observations that improved data quality is achieved during faster survey speeds (c. 10 knots).

Table 4. List of system crashes associated with the EM122 mulitbeam echo sounder hardware and software (SIS) during cruise NBP19-02.

Date	Time (UTC)	Problem/solution
5 FEB 2019	16:39	Reboot as data files not piping to rvdas
11 FEB 2019	18:46	SIS crash and reboot; loading background image
12 FEB 2019	01:42	Hard reset. EM122 not pinging.
16 FEB 2019	04:43	SIS crash and reboot; loading background image
23 FEB 2019	06:35	SIS crash and reboot; Grid Engine failure
23 FEB 2019	06:45	SIS crash and reboot; Grid Engine failure
25 FEB 2019	12:09	SIS crash and reboot
26 FEB 2019	01:42	SIS crash and reboot; Grid Engine failure
02 MAR 2019	07:36	SIS crash and reboot; Grid Engine failure
05 MAR 2019	07:14	SIS crash and reboot
07 MAR 2019	19:19	Hard reset. EM122 not pinging.
11 MAR 2019	20:15	SIS crash and reboot
13 MAR 2019	23:18	SIS crash and reboot; graphics card issue
15 MAR 2019	03:20	SIS crash and reboot; graphics card issue
18 MAR 2019	21:08	SIS crash and reboot; PPU synchronization failure

6.1.3. Calibration

Echo sounders routinely require calibration prior to undertaking significant tranches of hydrographic survey. The intention is to find biases in the installation angles of the sonar system and detect time synchronization biases relative to other attitude and positioning sensors onboard. It had been four years since the ship's EM122 had undergone a full calibration but no time had been specifically set aside to undertake calibration of the multibeam system on this cruise. BIST tests were undertaken at the very start of the cruise and reported no issues with the EM122 system.

i. Roll bias in survey data

North-east of the De Gerlache seamounts (JD37), whilst surveying on initial passage southwards, watch keepers identified a significant port-side bias in the incoming multibeam swath bathymetry

data. Further investigation revealed a consistent tilt on the gridded cross-track data that followed the ship position despite our changes in course. It was determined that a patch test (roll bias correction) would be required to correct the bias. The area south of the De Gerlache seamounts served as an ideal location to undertake the patch test because of the exceptionally flat sea bed and favourable sea-state at the time of acquisition.

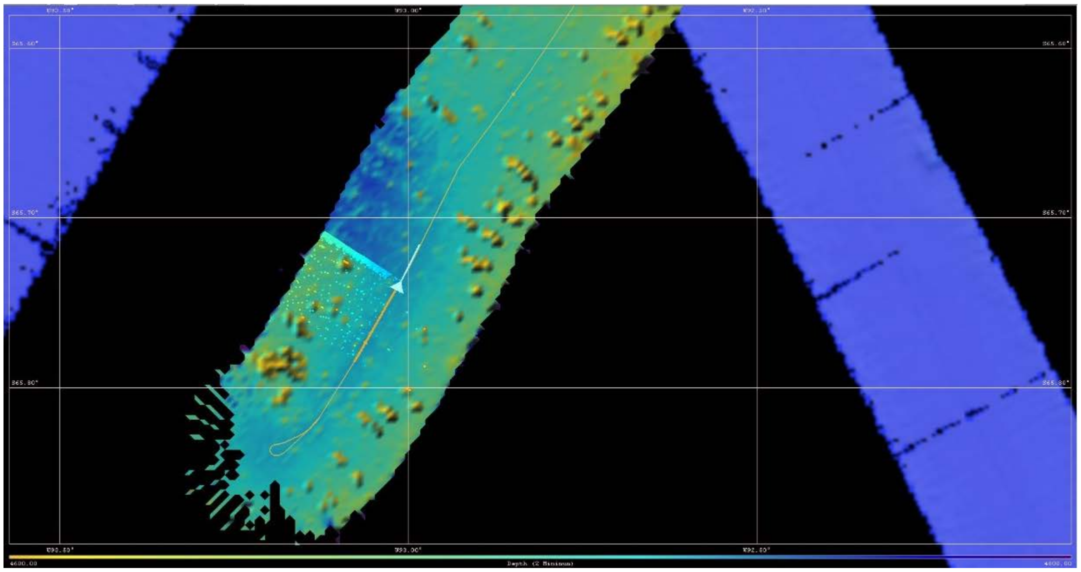


Figure 25. Screen-grab of 'Geographical' display from SIS showing shiptrack lines obtained during the patch test. A clear port-side roll bias is observable in the mis-match between overlapping swaths.

ii. EM122 Calibration procedure

Multibeam swath bathymetry data were acquired over a consistently flat portion of the sea-floor for approximately 1 hour. The survey was repeated on a reciprocal line with complete overlap (200%) coverage in order to obtain two entirely overlapping swaths with opposite headings (Fig. 25). The data were brought into SIS 'Calibration' window and data were analysed perpendicular to the shiptrack across four individual 1000 m-wide corridors that covered the full swath width. Offsets were clearlv visible in the overlapping tracks (Fig. 26). As a result of this analysis, a correction of -0.35˚ was applied to the roll, and the values stored in SIS (Fig. 27). They were subsequently applied in the 'Installation Parameters' menu of SIS. Pitch and heading were neither assessed nor changed during the calibration, but a QC of the data suggested no significant pitch problems (although we did not survey clear topographic features in the patch).

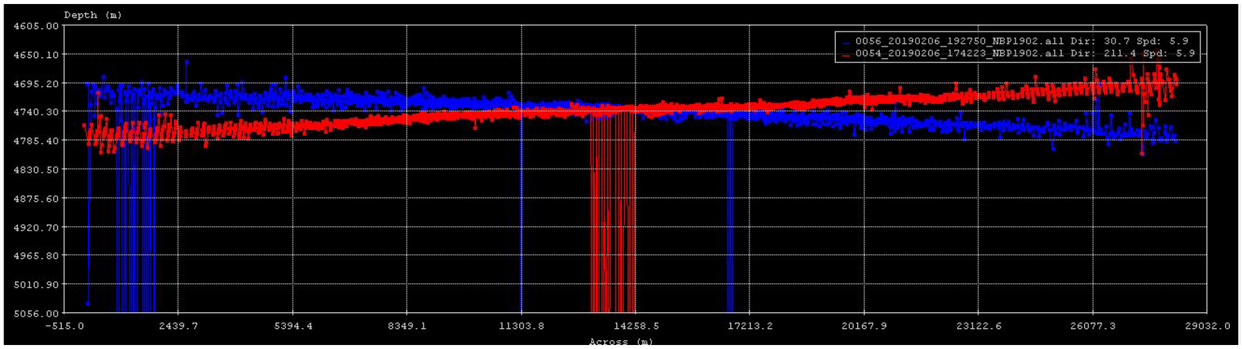


Figure 26. Line 54 (red) and Line 56 (blue) illustrating significant across-track offsets between overlapping swaths prior to calibration (JD37 of NBP19-02).

Figure 27. Initial sensor angular offsets, prior to EM122 calibration.

After logging resumed, the data were analysed again to check for additional bias. This confirmed that the roll correction had worked effectively.

iii. Results and recommendations

Unusually, the roll correction applied was the counter-sign of the pre-existing angular offset stored in the SIS system (with the effect that the correction brought the offset angle back to zero). This may be a simple coincidence but it is suspicious that the bias exactly matched the system offset, and was so large in the first instance. Without a history of changes to the transducer and installation offsets, we were unable to verify whether the roll bias has been a persistent or is a recent phenomenon. Although the data collected on NBP19-02 appear internally consistent, we would therefore recommend that special care is taken to check (and even re-survey if necessary) the installation offsets for the transducers (particularly for alignment), as well as the MRU, and GPS antenna, when the ship is next in dry dock. A full calibration of the EM122 consisting of corrections for roll, pitch, time delay, and heading should be performed – it is probably overdue.

iv. Lines used for roll calibration

The lines used for calibration were lines 54 and 56, belonging to the passage survey NBP1902a.

v. Step-by-step guide for performing a roll/pitch calibration in SIS

The Kongsberg manual for the EM122 misses out some key steps in guiding the user through a roll calibration. Here, we layout simple step-by-step instructions for performing a roll calibration in SIS. Note to save or make a note of the existing installation parameters before you make any changes to the angular offsets, as once applied you cannot undo the changes.

1. Obtain data needed for conducting the calibration. Start new lines after each turn.
2. Select the survey name to make it active in SIS
3. Open the Calibration window suite, using the drop down menu below ‘File’ (top left).
4. In Geographical window, make sure ‘stored shiptrack’ is checked from the top left menu.
5. Show SIS-based surveys also checked.
6. Press the ‘C’ button on the top bar of the Geographical window.
7. Zoom to desired lines on the map.
8. Ctrl-left mouse button and select lines (at least two), or use the ‘select lines’ menu in the Calibration tearout
9. Ctrl-right mouse button and select ‘create corridor’
10. Ctrl-left mouse button and click (and release) starting point of line
11. Ctrl-left mouse button and click (and release) the other end of the line
12. Draw the above line perpendicular to the track (across swath) for the roll correction.
13. Draw the line along the track for the pitch correction.
14. Set the corridor width in the calibration settings to 300-1000 m for deep water. This setting adjusts the amount of data involved in your analysis.
15. Data will appear in the Calibration window.
16. Manually set the min and max depths to focus on the true data and ignore bad pings. Can also use left mouse to draw a box over the data of interest.
17. Adjust the bias until the two swaths show a match.
18. Repeat the step in at least three different corridors along the track. Record each bias. Take an average of the bias from your measurements.
19. Press ‘Store’ to send the values directly to parameter list in the Installation Parameters > Sensor Setup > Angular Offsets

20. Make sure to stop pinging and logging, and verify that the new offsets have been applied by manually inputting the numbers into the Installation Parameters and pressing OK.
21. Check and ideally test that the new offsets have worked and have removed any problems in the incoming data.

6.2 Knudsen sub-bottom profiler performance

Kelly Hogan and Ali Graham

6.2.1 Description and operation

The Knudsen CHIRP 3260 sub-bottom profiler is a hull-mounted, deep water echo sounder configured to operate at two low frequencies (3.5 kHz and 12 kHz) in order to reach full ocean depths. The system emits a simple Chirp pulse over a range of frequencies (e.g. 2.3-5.3 kHz for the central frequency 3.5 kHz). The simple conical shape of the emitted pulseform results in a relatively large footprint size at the seafloor (30°) i.e., the Knudsen is not a parametric system. In order to prevent interference of the second CHIRP 3260 channel with the EM122 multibeam echo sounder data (both systems operate at 12 kHz), sub-bottom profiler data were only acquired with the 3.5 kHz frequency channel. The echo sounder uses data from several ancillary systems (GPS, inertial motion reference unit or MRU) in order to process and log sub-bottom information accurately. The system operates with a constant sound speed through water that is input by the user (in this case 1500 m s^{-1}) and transforms two-way travel time (TWT) to depth on-the-fly during acquisition. As a result, profiles are replayed in time-converted depth rather than TWT on the acquisition software; this is also the case for data replayed in the PostSurvey software.

Logging of sub-bottom profiler data began at 17:56 UTC on Julian Day 036, and the system was operated near continuously during the cruise until the RV/IB *Nathaniel B. Palmer* (NBP) re-entered the Chilean EEZ. In general, data was not acquired when on station apart from at coring locations to ensure that we had not drifted away from the selected sediment layers. One notable period when data was not logged was between 03:01 UTC on JD 051 and 19:25 UTC on JD052 when the vessel was approaching and then stationary at Rothera Research Station. Pinging and

logging of Knudsen CHIRP sub-bottom profiles was stopped for the final time at 06:34 UTC on Julian Day 081.

6.2.2 Standard settings

Typical parameter settings on the Knudsen EchoControl Client for deep water (continental slope and rise) and intermediate to shallow waters (continental shelf) are listed in Appendix A13. The absence of a synchronization unit on the NBP meant that the Knudsen was operated with an internal trigger throughout the cruise (i.e., the Knudsen was not synchronized with the EM122 multibeam echo sounder). However, the ping interval was manually adjusted so that it was not an integer factor of the ping cycle of the EM122 when regular interference was observed on the EM122 data. The Knudsen was operated with a Chirp source and a matched filter (correlator) and envelope processing were applied to incoming data within the EchoControl Client. The standard square-law envelope detect of the CHIRP 3260 system improves the signal-to-noise ratio of the echogram data by helping to extract the signal return from background noise. Various digital filters are applied to the data (see Usage Configuration settings in Appendix A13); rectangular filters were used for all options. It is important to use the same type of filter for both the signal filter and the transmit filter to aid correlation of the transmitted and received signals. The bottom tracker tool was not deemed reliable in areas with a rugged seabed and was therefore not used during the cruise. The profiler was most often run with the analog receiver gain set to manual with small adjustments made to help amplify the signal from the seafloor and sub-bottom sediments in varying water depths; time-variable gain (TVG) was also applied at times (see full list of settings in Appendix A13). Parameter settings used on NBP19-02 were saved in configuration files (.cfg) for both deep and shelf water depths; the files were:

NBP1902_deepwater_seds_5Feb2019.cfg

NBP1902_shelfdepths_Rothera_21Feb2019.cfg

6.2.3 Problems encountered

The Knudsen sub-bottom profiler performed reasonably well during NBP19-02. Reflections were imaged up to 30–40 m (40–53 ms TWT using a sound velocity of 1500 m s^{-1}, as is applied in the Knudsen acquisition software) below the seafloor in deep basins close to Thwaites Glacier where fine-grained, stratified sediment accumulations occur. Thicker sediment accumulations (50 m or 67 ms TWT) were also imaged in deep water on the lower continental slope and rise offshore the Amundsen and Bellingshausen seas and during transit to Punta Arenas.

Several minor operational/data quality problems were encountered during the cruise:

1. On JD 056 and 057 several dropouts of the position data were noted on the Knudsen Echo Control Client acquisition software (e.g. at 14:19, 18:39, 20:59, 21:59 UTC on JD 057). This resulted in readouts of “00 00.00000S 00 00.00000W” for latitude and longitude on the vertical timestamps of the sub-bottom profiler display. As a result, the GPS feed to the Knudsen was switched to the Seapath 200 GPS unit (from the Seapath 330) at approximately 12:00 UTC on JD 059.
2. Interference from side-lobe echoes was notable on sub-bottom profiles acquired during NBP19-02 and provided some concern when coming on to coring stations that the seabed might not be ideal for coring. This is assumed to be due to the relatively wide footprint of the Knudsen profiler, when compared with a parametric echo sounder for example, meaning that side-lobe interference from nearby objects is often seen in profiles.

6.2.4 Data outputs

Sub-bottom profiler data was logged directly to the two native Knudsen file formats: .KEA and .KEB. The former is an ASCII header file containing the metadata for each file, the second file is a binary data file that records the envelope data for each active channel (for NBP19-02 we only used one channel, 3.5 kHz). For every ping cycle one record is stored with header information and raw data and each record has a variable trace length. The ASCII file can be configured to log many data fields including echo sounder depth, time, and GPS position; the application records one output string for every ping cycle. For NBP19-02 all data fields were checked and recorded to the .KEA files.

It is possible to record to SEGY at the same time as logging .KEA and .KEB files. However, when this option was chosen the SEGY file sizes were incredibly large. After testing of the Knudsen Conversion Utility to convert .KEB files to .SGY files the option to record SEGY concomitantly during acquisition was switched off. All .KEB files were converted to SEGY format using the Conversion Utility at the end of the cruise.

A third party software (autoscreen.exe) was used to acquire screenshots of the sub-bottom profiles during NBP19-02. This software was installed on the acquisition PC and set to capture a screenshot image as a JPEG file at regular intervals e.g., 10-20 minutes. The interval was varied during the cruise according to water depth.

Full descriptions of the .KEA, .KEB and .SEGY file formats produced by the Knudsen are provided in the CHIRP 3260 documentation.

6.3 Acoustic Doppler current profilers

The information below is taken from an on board web page describing the acoustic Doppler profiler data (ADCP) acquisition and automated processing on the *Palmer*.

The *Palmer* has two Teledyne RDI ADCPs, both Ocean Surveyor models (phased array). One is 75kHz ("OS75"), one is 38kHz ("OS38"). The OS38 often reaches to 1000 m in good weather in its deep-profiling mode. In bad weather, low scattering conditions, or some speed/heading/sea state conditions that entrain bubbles under the transducer, the range is less. The OS75 range is impacted by a thick ice-protection window, and it only reaches 100m-150m in broadband mode and 400m-450m in narrowband mode.

Data acquisition for both ADCPs and the requisite ancillary navigation streams occurs via the UHDAS software, written by Eric Firing and Jules Hummon, University of Hawaii.

Fully automated data processing and plotting was done every 15min, and the data were copied to a location accessible via an intranet web page and via network share. The automated processing system includes corrections (from the Seapath) to the gyro heading, and as much editing as the

UHDAS software writers were able to automate. They recommend a final processing of the ADCP data set after the cruise. The biggest differences between the automated processing results and reprocessed data will likely be found under adverse conditions: shallow water, heavy seas, lack of scatterers, bad weather. Scientists are free to walk off the ship with copies of figures from the web page and the data distributed there but are cautioned that these data are not fully processed. If you intend on any serious use of these data, you will have to put the finishing touches on the data.

6.4 Sediment coring operations

Becky Totten Minzoni

Core locations were selected using a combination of swath bathymetry and sub-bottom CHIRP profiler data. In general, the deep troughs offshore Thwaites Glacier were found to have soupy and thick sediments, while cores collected from the slopes of shallow pinning points offshore the now-receded western Thwaites Ice Tongue and the Eastern Ice Shelf are characterized by glacimarine muds and pebble-rich, sandy mud likely resulting from sediment gravity flows. Cores collected from the top of exposed pinning points were characterized by silty glacimarine mud overlying stiff pebbly mud or till. In some cases, the deep trough accumulations appeared to be ~25 m thick in the Knudsen profiles, and we were unable to sample the entire section with our longest coring device, which totaled 6 m.

A Box corer, and a Megacore Multicorer, a 3 m Kasten corer, a 1.5 m Kasten corer, and a jumbo gravity corer, which can reach 6m with two barrels at its full length, were utilized to collect sediment cores during the NBP19-02 expedition. Section 4.2 and Appendices A2 and A3 provide further information on sediment cores collected during the expedition, including maps, profiles, and tables of the core locations and sediment recovery. Twenty-eight sediment cores were attempted during the cruise, including 9 Kasten cores (KC), 7 Jumbo Gravity Cores (JPC), 11 Megacores (MC), and one Box core (BC). Of these attempts, only one MC and one KC failed. All lithological descriptions were conducted by Dr. Totten Minzoni; descriptions are based on sediment color (Munsell Color Chart), texture, fossil content, and sedimentary structures. Core disturbance is noted where present. Kasten core descriptions can be found in Appendix A3 of this report.

6.4.1 Kasten Corer

As a general rule, the Kasten Corer is an efficient and robust coring tool for capturing both the longer sediment record and preserving the seafloor surface. Two types of Kasten corers were used during NBP19-02, both sharing the same collar assembly, but with two core barrel lengths, one 1.5 m-long and three 3 m-long core barrels. The Kasten corer consists of a 13 cm x 13 cm (5.5" x 5.5") cm barrel composed of stainless steel. The core head can be loaded with a maximum of 20 lead weights of 32 kg weight (70lbs). Twelve weights were used for the majority of the Kasten cores, until two Kasten cores near Thwaites Glacier (KC15 & KC19) fully penetrated the soft muddy sediment, and ten were used after that. While they were completely full, we do not believe that KC08, KC15, and KC19 over-penetrated the seafloor, because live benthic organisms were observed in the core tops. The 3m KC's were successful and all exceeded 1.7 m in length.

The first Kasten Core (KC01) lost its uppermost sediment due to some difficulty in operations. The HUGIN van on the port side of the aft deck required that the JPC track and the KC boot be positioned off center from the A-frame winch pulley. The MT's needed to place the KC into into the boot on the starboard side of the aft deck and needed to lay the core barrel down and secure it directly. After that, the boot was moved closer to center, and operations were smooth. All 3 m Kasten cores were deployed from the aft deck with the Hawbolt winch on the large A-frame.

The small 1.5 m-long Kasten Core was deployed with 8 collar weights. Only one 1.5 m Kasten core (KC18) was attempted, and it failed. This was either due to it falling on its side on the seafloor or washing out upon recovery.

6.4.2 Megacorer

The Ocean Scientific International (OSIL) Mega Multiple Corer is a framed rosette of core heads and tubes that have a shutter that drops below core tubes to seal them; the shutters trigger when the frame hits the seafloor. The Megacorer is ideal for preserving the sediment-water interface and can produce a sizable amount of sediment for analyses with twelve ~11 cm diameter core tubes, each ~60 cm in length. The Megacorer was used to target the seafloor surface and overlying water in supplement to the Kasten cores.

Of the 12 Megacore attempts, 11 were successful. The USAP Megacorer was new out of the box and had not been tested before the cruise. The first attempt (MC02) was in soft sediment near the Abbot Ice Shelf, and the core tubes were muddy, but the shutters did not trigger and the keys were still engaged. One MC tube did fire, however, returning ~10 cm of seafloor surface sediment (archive MC02z). The tube lost contact with the stopper at the bottom during extraction from the frame, however, and the water washed out. The 10 cm of sediment was saved on the stopper and archived and sampled for live foraminifera. The MT's shortened the safety lanyards on the MC frame to help enable triggering of the shutters. A medical evacuation brought the ship to Ryder Bay, near Rothera Station, where the team again deployed the Megacorer in shallow water with great success seaward of Sheldon Glacier (MC03). Eleven out of 12 tubes were full of ~50 cm of greenish-grey soupy muddy sediment and the sea floor surface and bottom water was well preserved in the coring process. Live benthic organisms were abundant in the core tops.

The next Megacore attempt (MC05) near Thwaites Glacier resulted in empty tubes, with only one tube triggering and returning ~40 cm of sediment that washed out during processing. Soupy, clay-rich sediment at the seafloor likely prevented triggering and recovery of the coring tubes. Therefore, a 'snow shoe', consisting of cut plywood, was attached to the base of the core frame. This improved recovery of the soft soupy sediments somewhat, returning two core tubes of ~40 cm sediment and overlying water (MC06).

The team also tried an older and lighter multicorer device in the soupy sediment. This marginally improved recovery, with 2 out of 12 core tubes returned in the Deep Trough on the Western side of Thwaites Glacier (MC09). The older multicore with the snowshoes also performed well in the area proximal to Thwaites Glacier, where the seafloor is exceptionally soft and soupy. MC12, MC14, and MC16 recovered 8, 3, and 4 core tubes, respectively.

In the Deep Trough west of the Eastern Thwaites Ice Shelf, another successful Megacore was collected (MC22, with 8 full tubes) after a failed attempt that had issues with winch tension on the seafloor (MC21). MC26 was taken in the area east of the Eastern Ice Shelf, and only recovered two tubes, again likely due to soft seafloor sediment preventing triggering of the shutters.

6.4.3 Box Corer (BC)

To explore additional coring methods to preserve the seafloor and bottom water, a deployment of the Ocean Instruments, Inc. BX-650 MK-III Box Corer was attempted in Cranton Bay, south of Canisteo Peninsula in the eastern Amundsen Sea. Box Core 28 was nearly full, with ~40 cm of soupy mud and abundant benthic and neritic sea life in the overlying water. There were some issues removing the box from the core device, due to sticking that may have been caused by lack of use, but minimal disturbance and samples of the bottom water was achieved.

6.4.4 Jumbo Gravity Corer (JPC)

The Jumbo Gravity Corer is custom built gear from WHOI and USAP, from here referred to as JPC to clarify core diameter according to convention in operations aboard the *R/V Nathaniel B. Palmer*, although no piston was used. The JPC is an excellent tool for sampling thick sedimentary sections, especially where hard surfaces and cohesive sediments like tills are expected. The JPC gear does not, however, preserve the seafloor surface because it is a high impact operation. In all cases, the uppermost soupy sediment poured out of the barrel when it was brought on deck and secured on metal sawhorses. The JPC consists of a 2.5 ton weight referred to as a “bomb” that sits above the heavy steel core barrel, which included two 3-m sections (6m total length) on NBP19-02. A PVC liner with threaded connections (and pre-labeled with archive (A) and sample halves(S)) was inserted inside the metal barrel and a catcher and heavy steel cutter was threaded onto the end of the barrel.

The first JPC (JPC07) returned less sediment than the KC04 at the same site, which may have been due to a core catcher that was not optimized for soft sediment. The bomb and flange returned with mud on it, thus the soft sediment may have washed out of the catcher. Therefore, a more flexible catcher was used at the next site, with great success. JPC 10 returned 4.1 m of sediment. The same core catcher was used for all succeeding sites with good recovery.

The final JPC, however, likely over-penetrated the expanded soft sediment to the east of the Eastern Thwaites Ice Shelf. JPC 25 collected mud all the way up to the bomb, and even included mud in its upper barrel, and the total archived section is 6.1 m.

6.5 CTD system

B.Y. Queste

Details of the instrumentation attached to the CTD and the software processing chain are included in the data report provided by NBP IT at the end of the cruise.

The 24 bottle SeaBird (SBE) rosette equipped with 24 12L Niskin water bottles was used for all casts on cruise NPB19-02. Standard SeaBird Software Version Seasave V 7.26.1.8 was used for data collection and conductivity cell thermal mass correction (The SBE-11plus manufacturer recommended values were used: thermal anomaly amplitude, α=0.03, thermal anomaly time constant 1/β=7.0). Sensors installed on the CTD SBE 11plus V 5.0 include the following with their respective calibrations used in this set up. The actual calibration profiles can be found in the headers of the respective profiles.

Temperature #1, SN 2438, Calib: 29-Nov-16

Conductivity #1, SN 1431, Calib: 22-Nov-16

Pressure, Digiquartz with TC, SN 1130, Calib: 23-Apr-18

Temperature #2, SN 5185, Calib: 07-Feb-17

Conductivity #2, SN 1852, Calib: 14-Feb-17

Oxygen SBE 43 #1, SN 0080, Calib: 21-Nov-17

Oxygen SBE 43 #2, SN 0150, Calib: 11-Apr-18

Fluorometer WET Labs ECO-AFL/FL, SN FLRTD-855, Calib: 16-Apr-18

Transmissometer WET Labs C-Star, SN CST-892DR, Calib: 10-Nov-16

Altimeter, SN 51520, Calib: unknown

PAR/Irradiance Biospherical/Licor, SN 4469, Calib: 17-Oct-16

SPAR/Surface Irradiance, SN 20546, Calib: 8-Mar-17

Pressure, temperature, transmission and PAR taken as is and not calibrated. Conductivity is detailed in the salinometry section. Fluorescence will be calibrated post cruise following analysis of filter samples. Data quality in general was good. No major malfunction of any instrument on the CTD was recorded. No obvious spikiness found in the data.

Cast 108 was split into two (108 and 108b, for down and up casts respectively) because of a software glitch, all profiles are good.

Cast 74 showed low values in the primary conductivity sensor most likely linked to freezing inside the cell. The CTD was flushed and restarted. Secondary conductivity looked good.

6.6 Salinometry

Peter Sheehan

Salinometry measurements were made from water samples in order to calibrate the primary and secondary conductivity sensors on the CTD rosette. Samples were measured on a Portasal 8410A, serial number 71938, in a temperature-controlled room. The temperature of the room varied between 19 and 21°C during all measurement periods. The salinometer was calibrated by Guildline on 22nd July 2015. It was inspected by the manufacturer on 19th August 2015. A service that was due in October 2016 and an alignment that was due in October 2017 were missed. The stated accuracy of the salinometer is 0.0003 mS sm^{-1}, i.e. 0.003 PSU. The bath temperature of the salinometer varied between 22.013 and 22.014°C during the cruise.

Calibration

A reference calibration, zero calibration and standardisation were performed on the salinometer on 18th February 2019, prior to running any samples.
The values for the reference calibration (Table 5) were satisfactory according to the manual, i.e.: (1) positive and negative reference values were stable between 19750 and 19999; (2) positive and negative reference values were stable within ±2 counts after 10 cycles; and (3) positive and negative reference values remained stable within ±2 counts after 10 minutes.

Five zero calibrations were necessary. The resulting values for the zero calibration were satisfactory according to the manual. On the fifth calibration, the zero value was -0.00020 (between ±0.00075, as required), and the calibration resulted in a zero conductivity reading of 0.00000.

Prior to standardisation, the standby conductivity reading on the salinometer was 4444508358 (18th February 2019, 16:30 GMT), indicating the conductivity readings had drifted significantly since the previous calibration. The salinometer was standardised using IAPSO standard seawater (batch P149, 5th October 2007, K_{15} = 0.99984).

Measurement procedure

Readings were logged using the Ocean Scientific International: Ocean Data Logger version 1.2 computer program, which was plugged into the salinometer. At the start of each session, a calibration conductivity ratio was obtained using IAPSO standard seawater: the same batch as was used for the initial standardisation. The salinometer was flushed five times with IAPSO standard seawater prior to obtaining a calibration conductivity ratio. The difference between the calibration conductivity ratio thus obtained and the true conductivity ratio of IAPSO standard seawater was assumed to be due to drift in the salinometer; Ocean Data Logger added this difference to all readings taken during that session.

Table 5. Values from the reference calibration.

Cycle	Negative reference	Positive reference	Reference
01	19836	19835	39730
02	19836	19836	39729
03	19835	19835	39729
04	19835	19835	39729
05	19835	19835	39729
06	19835	19835	39729
07	19835	19835	39729
08	19835	19835	39729
09	19835	19835	39729
10	19835	19835	39729
Values remained unchanged after 10 minutes			

The salinometer was flushed three times with each sample prior to taking readings. Three ensembles of readings were taken from each sample as standard. For each ensemble, Ocean Data Logger took 10 readings and calculated the mean. Additional ensembles were taken when the conductivity ratios varied considerably; anomalous ensembles were removed from the record. An anomalous ensemble for a given sample was taken to be one for which the calculated practical salinity differed from that of the other two (or more) ensembles by more than ±0.003 PSU, the stated accuracy of the salinometer. Ocean Data Logger calculated the mean practical salinity for each sample from all remaining ensembles.

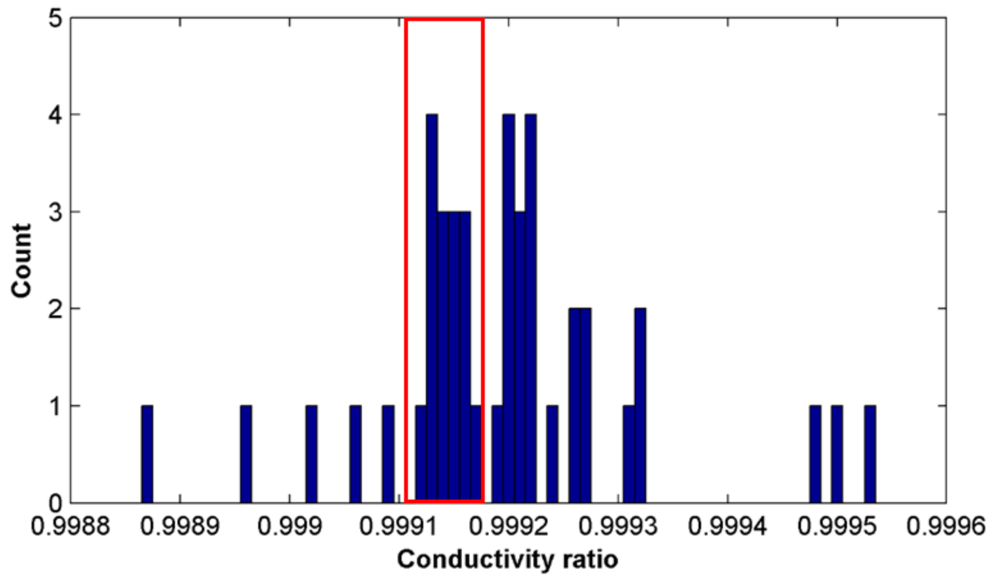


Figure 28. Conductivity ratios obtained from IAPSO standard seawater. The red box indicates the range of conductivity ratios taken to be that of IAPSO standard seawater given instrument drift.

Instrument performance

Salinometer performance was poor. Of 39 sets of triplicate bottle samples taken from the same niskin bottle, the practical salinities of only 13 sets agreed to within ±0.003, the stated accuracy of the salinometer. This does not give confidence in readings for which triplicates were not available. In addition, the salinometer would sometimes give readings from the same sample bottle that differed by more than 0.003. Where this happened, the sample bottle was removed, gently mixed and a second set of readings taken once the salinometer had been flushed through a further three times using the sample. The salinometer would generally then provide ensembles that agreed to within ±0.003 PSU. Given the poor replication on triplicate samples and the drift in readings during

single samples, the salinometer is assumed to have poor precision. Furthermore, this lack of precision could affect the calibration readings taken at the start of each session, which does not give confidence in the salinometer's accuracy.

Once these errors became apparent, the calibration of the salinometer was tested on five occasions using IAPSO standard seawater. Based on these readings (Figure 28), the measured conductivity ratio for IAPSO standard seawater is assumed to be 0.99914 ±0.00003 (red box in Figure 28). When calculating the error of the conductivity sensors on the CTD rosette, only salinometry readings from sessions with an initial calibration reading within this range are used.

Results

The salinities measured using the salinometer are assumed to be correct. Using the temperature measured by the CTD at the depth each bottle sample was obtained, the true conductivity at that depth is calculated. This calculation was performed for both the primary and secondary conductivity sensor on the CTD. The ratio of the salinometer-calculated conductivity and the CTD-measured conductivity is presented in Figure 29 as a function of the time of each CTD cast. Ratios greater than 1 indicate that the CTD is reading too fresh; values less than one indicate that the CTD is reading too saline. Ratios greater than 1.0005 and less than 0.9995, i.e. out of the 0.05% error range, are discounted, given the poor precision of the salinometer. Using good readings (i.e. good calibrations and within 0.05% error; bottom panel in Figure 29), the root mean square difference between the salinometry-calculated conductivities and the *primary* CTD conductivities is **0.0046 mS cm^{-1}**, and the mean conductivity ratio is **1.000035** (n = 58). The root mean square difference between the salinometry-calculated conductivities and the *secondary* CTD conductivities is **0.0052 mS cm^{-1}**, and the mean conductivity ratio is **1.000083** (n = 57). Both the primary and secondary sensor are reading too fresh.

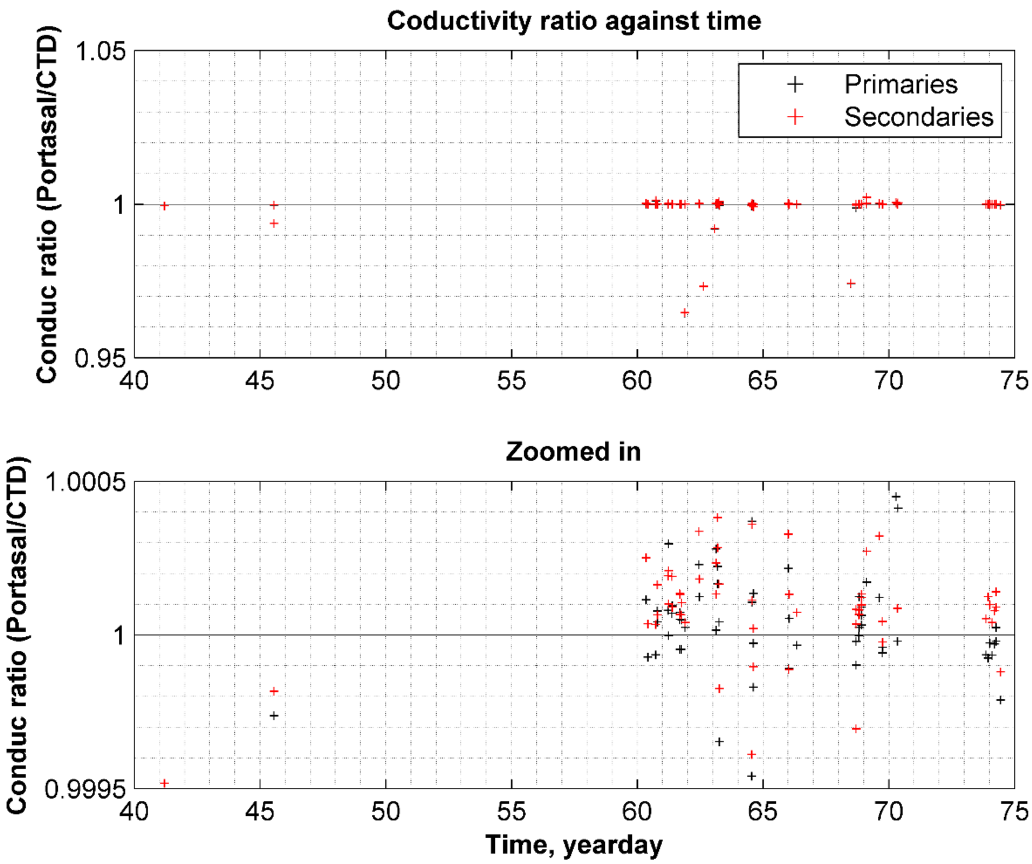


Figure 29. Ratio of salinometry-calculated conductivity to CTD-measured conductivity against time of each CTD cast. Top: over the full range of the data. Bottom: over the range 1±0.0005, i.e. the 0.05% error range.

6.7 Glider operations

Full details of glider deployment and recovery procedures and performance are included in section 4.5.

6.8 Satellite Relay Data Logger performance

Lars Boehme

Pre-deployment quality check

All CTD-SRDLs are calibrated by the manufacturer before shipping. However, it has proven to be useful to compare the CTD-SRDLs to a ship-based CTD system. All CTD-SRDLs were therefore attached to the ship-based CTD frame lose to the ship-based CTD system for at least one CTD cast to depths between 500m and 1640m. The metal frame as well as the attachment using cable ties is thought to effect the conductivity measurements, so that only the pressure and temperature sensors were checked (Table 6).

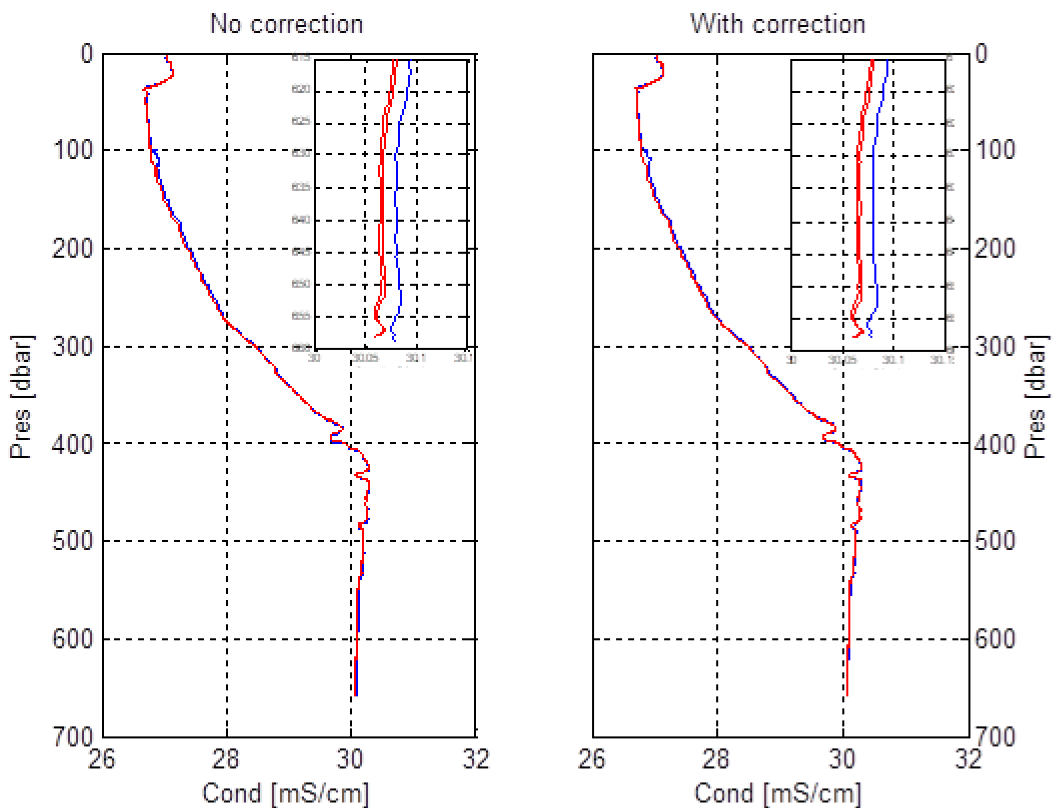


Figure 30. *Figure showing conductivity measurements by CTD-SRDL #14864 and CTD cast #2. Panel on left shows CTD-SRDL measurements without pressure correction, while panel on right shows corrected data. Inserts show the deepest measurements.*

The pressure sensors operated within the specifications as given by the manufacturer. All sensors did measure slightly too high at high pressures and we calculated a correction value to be added to the pressure measurements in post-processing resulting in a new pressure P_{new} of

$$P_{new} = P_{obs} + fP_{obs}$$

with the correction factor f as given in Table 6. This factor is relatively low resulting in a correction of about 3 dbar or less for each 1000 dbar pressure increase. However, it does improve the data as shown in figure 30.

Temperature data was compared for each cast between the CTD-SRDL and ship-based CTD system. Differences were generally very small in the order of 0.01°C or less and need to be estimated in more detail after the cruise. However, 4 CTD-SRDL showed some strong impacts of pressure on the temperature readings. These effects were consistent neither within nor between tags, but present during all CTD casts. An example is shown in figure 31. CTD-SRDLs with numbers #14865, 14866, 14889 and 14896 were therefore not deployed.

Deployments

Catching and anaesthetizing seals followed standard protocols as used in the past and approved during the ethical review process. No problems were encountered. One subjective result is that the Weddell seals seem to respond better to an initial intravenous injection of the anaesthetic drug Zoletil at a dose of 0.4-0.5ml per 100kg body weight instead of using a dart. This was sometimes followed up by a second intravenous injection at a dose of 0.06-0.1ml per 100kg body weight after 15-20min when deemed necessary.

Post-deployment data

Data collected by the CTD-SRDLs is received in near real-time. We were therefore able to start estimating salinity offsets (Table 6) that have to be applied to the data collected and are a result of the attachment of the sensor to the seal. These corrections will improve the real-time data. Nevertheless, a thorough delayed-mode quality control procedure needs to be applied after all data were collected and is estimated to start in November 2019.

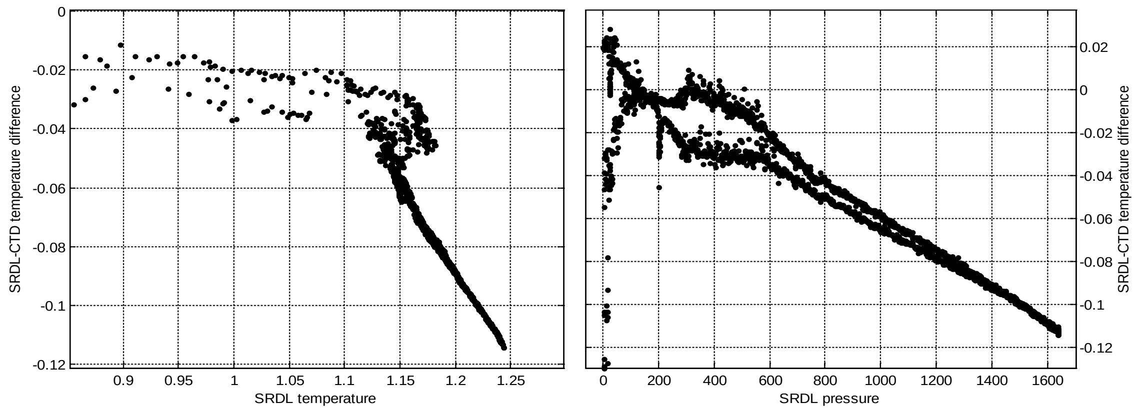


Figure 31. Temperature differences between CTD-SRDL and ship-based CTD system over temperature (left) and pressure (right).

Table 6. Table showing the corrections for data collected by CTD-SRDLs as determined to date.

SRDL Body number	CTD Casts	Pressure correction factor *f*	Temperature Correction	Salinity Correction
14863	2	-0.0016	*TBD*	-0.19
14864	2,8	-0.0014	*TBD*	-0.14
14865	9,70	-0.0022	*TBD*	*TBD*
14866	9,70	-0.0024	*TBD*	*TBD*
14867	2	-0.0012	*TBD*	-0.30
14868	9	-0.0021	*TBD*	*TBD*
14869	2,8	-0.0020	*TBD*	-0.08
14870	2	-0.0033	*TBD*	-0.12
14871	9,70	-0.0034	*TBD*	0.04
14872	2	-0.0022	*TBD*	0.02
14889	2,8,9,70	-0.0010	*TBD*	*TBD*
14891	2,8	-0.0001	*TBD*	*TBD*
14894	2,8,9	-0.0025	*TBD*	0.09
14896	9,70	-0.0019	*TBD*	*TBD*
14897	2,8	-0.0001	*TBD*	*TBD*
14898	9	-0.0006	*TBD*	-0.06

6.9 Hugin AUV and cNODEs

A.K. Wåhlin

The Hugin system itself proved very reliable. The biggest challenges were encountered during recovery. Recovery was done by launching a small workboat (zodiac) into the sea and towing Hugin alongside it back to the *Palmer*. The workboat also assisted in attaching the lifting bridle to Hugin. After the bridle was attached, the workboat moved away and Hugin was lifted onto deck using the ship's A-frame. Launch was done by lifting Hugin into the water using the A-frame and guided by guidelines. When Hugin was in the water a quick-release hook was opened after which the Hugin drifted away from the ship (sometimes aided by a small wash from the ship). On one occasion the quick-release got stuck, but the situation could be resolved with a boat hook. The occasions during which the recovery procedure was challenging all had worse weather or ice conditions than predicted at the start of the mission. A practice of having the AUV loiter at a safe depth until good recovery conditions and/or position could be assured was developed and employed in all the later missions, and will be incorporated as 'best practice' in future operations. This means that the AUV will not surface until it is manually commanded to do so. The acoustic link communication with cPap proved reliable. The best communication was obtained by lowering the cPap into the water maximum cable out (about 40 m) and turning off the ship's multibeam to avoid disturbance. cNODE beacons were used to aid the navigation. They were a good help to lower the navigation uncertainty, but the range turned out to be only 1 km. They were also limited in direction so that they worked best when the AUV was diving at approximately the same depth as their deployment position which also limits their usability. After the initial trials it took approximately 30 minutes to deploy and to recover one cNODE. Triangulation was mostly not needed (triangulation adds one hour to the deployment time). The stock of spare parts brought on board were mostly deemed adequate, with the exception of spare weak links for the rudder pins. Those will be brought in future cruises (minimum same number of weak links as spare rudders).

6.10 Expendable bathythermograph deployments

Kelly Hogan and Ali Graham

Expendable bathythermograph (XBT) probes were deployed intermittently during the cruise to provide sound velocity profile data for calibration of the EM122 multibeam echo sounding system on transit and when there were indications of changes in surface water properties in between CTD casts. A total of 12 Sippican Deep Blue XBT probes were deployed during NBP19-02 with 9 of those acquiring depth and temperature data profiles to their design limit of 800 m (water depth), or to the depth of the seafloor if it was shallower than 800 m. Metadata from the 9 successful casts are listed in Table 1 (page 19) and Appendix A8. Two XBT probes failed to connect to the WinMK21 software during deployment and were therefore replaced with new probes prior to launch. One XBT probe (TD_00043.RDF) only acquired data to 400 m (in a water depth of >3500 m) and so was repeated with a new probe (TD_00044). In the WinMK21 software it is possible to extend the depth rating of the probe and this was done during the latter half of the cruise, extending the acquisition depth to 900 m.

XBT launches were performed by the ETs and communicated to the Forward Dry Lab via radio where a scientist watched the WinMK21 software and relayed information from the software. The PC in the Forward Dry Lab ran WinMK21 version 3.0.5. On the RV/IB *Nathaniel B. Palmer* XBT probes are launched near the stern of the vessel from the port side; the launcher is connected to a reel on Deck 01 aft of the helideck and pulled out to launch over the port side of the vessel.

6.11 Gravity meter

Rob Larter

The Bell BGM-3 shipborne gravity meter (S/N 210) that is permanently installed on the *Palmer* ran throughout the cruise without any problems. Ties to base station outside the harbour administration building were conducted before and after the cruise (Appendix A12).

6.12 Mooring instrumentation

Mark Barham

The BAS moorings are relatively simple and lightweight, constructed of 12 mm Gleistein Tasmania braid-on-braid polyester and 8 mm 12-strand single-braid polyurethane-coated polyester (originally Samson Tenex, more recently Maffioli Evolution Splice), with 12 mm 3-strand polypropylene for recovery lines. Floatation comprises strings of Vitrovex glass spheres mounted on 3 m and 5 m Kevlar ropes using Vitrovex's Eddygrip swivel system. At the top of the moorings 9 inch Neptunplast trawl floats are employed. Where instruments and floatation are clamped onto the mooring line, a section of 12/8 mm inner diameter plastic hose/tubing is used as strain relief. The clamps for the Aquadopps are custom Delrin blocks, based on a design from Bruce Huber at LDEO. The Aqualoggers are attached directly to the rope using size 1M stainless steel Jubilee clips (hose clamps). All moorings are anchored to the seabed using old steel train wheels weighing approximately 370-410 kg each. Connecting the anchor to the mooring are two IXSEA Oceano 2500S (AR861) acoustic releases, configured in tandem in an either/or release configuration. The only exception to this is Trough_E which was deployed on a single AR861 release.

The redeployed moorings (mid-shelf and PIG_S) contain a combination of Nortek Aquadopp DW (3000 m) single point current meters, Seabird Electronics SBE-37SM Microcat CTDs (un-pumped, 2000 m rated), Aquatec Aqualogger 520PT pressure/temperature loggers (512 kb memory, 1000 m rated) and RBR SoloT thermistors (1700 m rated). In addition, PIG_S was also fitted with an RBR concerto3 CTD (2000 m rated).

Moorings that were not recovered during this cruise, notably Trough_E, Trough_W and the original PIG_S, comprise the same instrumentation, other than the thermistors are Aquatec Aqualogger 520T (temperature only) loggers (512 kb, 1000 m rated). The original PIG_S mooring also has a Teledyne RDI 300-kHz Workhorse Sentinel ADCP housed within an in-line Flotec 33-inch syntactic foam buoy.

Instrument configurations for mid-shelf and PIG_S moorings are provided in Table 7 below. Configurations for the original PIG_S, Trough_E and Trough_W can be found in RV *Araon* cruise report ANA06B.

Table 7. Mooring instrumentation parameters.

	Aquadopp DW	SBE37-SM Microcat	RBR Concerto3 CTD	Aqualogger 520TP	RBR Solo3T Thermistor
Sampling interval	600 s	300 s	300 s	600 s	300 s
Average interval	60 s	n/a	n/a	n/a	n/a
Blanking distance	0.5 m	n/a	n/a	n/a	n/a
Battery	1 Simpower custom battery: 36 SAFT LS14500	12 SAFT LS14500	8 SAFT LS14500	1 SAFT LS14500	1 Duracell Industrial AA

During the cruise, all CTDs and thermistors were sent down on the vessel CTD rosette as a means of calibration. Where instruments had been recovered from a mooring, these were also deployed on the CTD for a post-deployment calibration cast. The RBR Concerto3 CTD and Solo3T thermistors were not deployed on the CTD rosette as they had recently undergone factory calibration (Dec 2018 and Jan 2019 respectively). Microcats s/n 8531 and 8542 were not sent down for the same reason, having both been factory calibrated in October 2017.

6.13 Navigation and vessel motion systems

Ali Graham

6.13.1. Seapath 330

The Seapath 330 is a combined GPS and motion reference unit that provides primary navigational data for the Knudsen 3.5 khZ Chirp sub-bottom profiler, as well as location information for other underway scientific instruments on the vessel. For significant portions of work in the southern Amundsen Sea embayment, the S330 experienced regular dropouts meaning that recorded Knudsen profiles frequently contained no navigational data.

6.13.2. Seapath 200

The Kongsberg Seapath 200 is the secondary GPS unit for the vessel combined with its own MRU distinct from the S330.

6.14 Data logging system (RVDAS)

Kelly Hogan

The Research Vessel Data Acquisition System (RVDAS) was developed at Lamont-Doherty Earth Observatory of Columbia University and has been in use on the RVIB *Nathaniel B. Palmer* for many years. Data logged by various shipboard instruments was ported through RVDAS during NBP19-02 and was divided into two general categories: underway and navigation. On board, raw and processed data were stored on an independent linux server (Discovery) that is mapped to all shipboard PC computers e.g., Q:\rvdas and Q:\process for raw and processed data, respectively. Within the 'rvdas' folder data was separated into the two categories 'nav' and 'uw'. Each instrument or sensor produces a data file named with its channel ID which is then processed daily in order to calibrate and convert data values into useable units, and as a quality-control measure.

The naming convention for data files produced by the sensors and instruments is:

NBP[CruiseID][ChannelID].dDDD

Example: NBP1902adcp.d034

- The CruiseID is the numeric name of the cruise, in this case, NBP1902.
- The ChannelID is a 4-character code representing the system being logged. An example is "adcp," the designation for the underway acoustic doppler current profiler.
- DDD is the Julian Day of year the data was collected.

6.14.1 Sensors and instruments

Data is received from the RVDAS system via RS-232 serial connections; all times are reported in UTC and are synchronized on to a GPS receiver. A time tag is added at the beginning of each line of data in the form:

yy+dd:hh:mm:ss.sss [data stream from instrument]

where: yy = two-digit year
ddd = day of year
hh = 2 digit hour of the day

mm = 2 digit minute

ss.sss = seconds

The delimiters that separate fields in the raw data files are often spaces and commas but can be other characters such as : = @. Occasionally no delimiter is present. Care should be taken when reprocessing the data that the field's separations are clearly understood.

Tables 8 and 9 below provide information on the data streams acquired during NBP19-02 for both the underway and navigation data recorded by RVDAS.

Table 8. Data types and strings recorded by the RVDAS system in the navigation folder.

Measurement	String ID	Collection Status	Rate	Instrument
Acoustic Doppler Current Profiler	adcp	Continuous	1/sec	UHDAS
GPS	gp02	Continuous from JD057	3/sec	Furuno GP-330B
Heading	gyr1	Continuous	0.2/sec	Yokogawa Compass
Gravimeter	PCOD	Continuous	1/sec	BGM3/210
Heading, speed, course, GPS, heave, roll, pitch	s330	Continuous	1/sec	Seapath 330 GPS
Heading, speed, course, GPS, heave, roll, pitch	seap	Continuous	1/sec	Seapath 200 GPS

Data were acquired by the Furuno GPS only after JD057 because of multiple dropouts of the Seapath 330 GPS, which acts as the primary GPS feed for several ship's systems. As a result, the Furuno GPS was activated from JD057 as a secondary 'back-up' GPS to the Seapath 200. Note that depths recorded on the Knudsen Chirp echo sounder ('knud') are depth-converted using a constant sound velocity (set to 1500 m s^{-1}) and thus are not representative of true seafloor depths.

Table 9. Data types and strings recorded by the RVDAS system in the underway folder. *Meterological parameters include air temperature, relative humidity, wind speed/direction, photosynthetically available radiation (PAR), shortwave radiation (PSP), long wave radiation (PIR), and barometer.

Measurement	String ID	Collection Status	Rate	Instrument
Winch (Baltic Rm)	Bwnc	During winch operations	0.3/sec	LCI-90i
CTD depth and altimeter	Ctdd	During CTD operations	25/sec	CTD
Winch	cwnc	During winch operations	0.3/sec	LCI-90i
Gravimeter	grv1	Continuous	1/sec	BGM3/210
Transmissometer, Fluorometer	hdas	Continuous	0.5/sec	WetLabs C-Star, WetLabs FLRTD
Bathymetry	knud	Continuous	varies	Knudsen Chirp
Bathymetry	mbdp	Continuous	varies	Kongsberg EM122
Meterological parameters*	mwx1	Continuous	1/sec	RM Young 41382LC, Gill Instruments 1390-PK-062, RM Young 61201, Biospherical Instruments QSR-2200, Eppley PIR, Eppley PSP
Fluorometer (digital output)	ndfl	Continuous	0.5/sec	Wetlabs FLRTD
pCO_2	pco2	Continuous	0.017/sec	LDEO instrumentation
GUV	pguv	Continuous	2/sec	Biospherical Instruments GUV-2511
Ocean surface temperature	rtmp	Continuous	1.2/sec	Sea-Bird SBE 38
Conductivity	tsg1, tsg2	Continuous	0.5/sec	Sea-Bird SBE 45
Winch (trawl)	twnc	During winch operations	0.3/sec	LCI-90i

Raw and processed data sets from RVDAS are included in the data distribution DVD provided to the cruise PIs. The two categories, underway and navigation, can be found on the distribution media as subdirectories under the top level rvdas directory: /rvdas/uw, and /rvdas/nav. For full details on individual data strings and a complete list of the data distribution please see the ASC NBP1902 Data Report.

7 Acronymns

ADCP	Acoustic Doppler Current Profiler
ARGOS	A satellite relay system for scientific data transmission
ASC	Antarctic Support Contract
ASCII	American Standard Code for Information Interchange
ASE	Amundsen Sea Embayment
AUV	Autonomous Underwater Vehicle
BAS	British Antarctic Survey
BBC	British Broadcasting Corporation
BC	Box Core(r)
BIST	Built-In Self Test
CDW	Circumpolar Deep Water
CHIRP	An acoustic system using a swept frequency transmission pulse
CTD	Conductivity Temperature Depth (cast/instrumentation)
DLR	Deutsches Zentrum für Luft- und Raumfarht (German Aerospace Center)
ECO	Edison Chouest Offshore (operator of RV/IB *Nathaniel B. Palmer*)
eDNA	Environmental Deoxyribonucleic Acid
ET	Electonics Technician
GHC	Geological History Constraints (ITGC project)
GPS	Global Positioning System
IAPSO	International Association for the Physical Sciences of the Oceans
IBCSO	International Bathymetric Chart of the Southern Ocean
IBRV	Ice-Breaking Research Vessel (prefix used from the Korean vessel *Araon*)
IT	Information Technology Technician
ITGC	International Thwaites Glacier Collaboration
IXSEA	A manufacturer of oceanographic equipment
JD	Julian Day
JGC	Jumbo Gravity Corer(r) (JPC used in gravity coring mode)
JPC	Jumbo Piston Core(r)
JPEG	Joint Photographic Experts Group standard compressed image format
KC	Kasten Corer(r)

MBES	Multibeam Echo Sounding System
MC	Megacore(r)
MLT	Marine Laboratory Technician
MMT	Marine Map Tech (technical support provider for Hugin AUV)
MPC	Marine Projects Coordinator
MRU	Motion Reference Unit
MT	Marine Technician
NBP	RV/IB *Nathaniel B. Palmer*
NERC	Natural Environment Research Council (UK)
NSF	National Science Foundation (USA)
NSIDC	National Snow and Ice Data Center (USA)
OFIC	Ocean Forcing of Ice-Sheet Change (a NERC National Capability project)
OSIL	Ocean Scientific International Ltd (a manufacturer of oceanographic equipment)
OSL	Optically-Stimulated Luminesence
PAR	Photosynthetically Active Radiation (sensor)
PIB	Pine Island Bay
PIG	Pine Island Glacier
PRI	Public Radio International
RDI	RD Instruments (a manufacturer of marine acoustic equipment, part of Teledyne Technologies Inc.)
RHIB	Rigid-Hulled Inflatable Boat
RSL	Relative Sea Level
RVDAS	Research Vessel Data Acquisition System
RV/IB	Research Vessel/Ice Breaker (prefix used for the *Nathaniel B. Palmer*)
SBE	Sea-Bird Electronics (A manufacturer of oceanographic equipment)
SCO	Science Coordination Office (of ITGC)
SEGY	Society of Exploration Geophysicists seismic data exchange ‘Y’ format
SES	Southern Elephant Seal
SIS	Seafloor Information System (Kongsberg MBES operating software)
SPAR	Surface Photosynthetically Active Radiation (sensor)
SRDL	Satellite Relay Data Logger

SVP	Sound Velocity Profile
TARSAN	Thwaites-Amundsen Regional Survey and Network Integrating Atmosphere-Ice-Ocean Processes (ITGC project)
THOR	Thwaites Offshore Research (ITGC project)
TVG	Time Variable Gain
TWT	Two-Way Time
UHDAS	University of Hawaii Data Acquisition System
UKRI	UK Research and Innovation
UTC	Coordinated Universal Time
UTMB	University of Texas Medical Branch
WES	Weddell Seal
XBT	Expendable Bathythermograph (probe/system)

8 Recommendations

In the light of our experiences on the cruise we make the following recommendations:

1. Early in the cruise the EM122 multibeam echo sounding system was found to be significantly out of calibration, and we understand it had been four years since a full patch test calibration had been conducted. The corrections determined from the patch test data we collected exactly reversed the effect of parameters already stored in the SIS system, casting suspicion on the parameters derived from survey of the installation offsets of the transducers and/or MRU. We recommend that a) survey of these installation offsets should be repeated when the ship is next in dry dock, b) a copy of the report should be kept on board, c) a log should be maintained of patch test calibration results, and d) the latter should be conducted at least annually.
2. A sonar synchronisation system (e.g. a Kongsberg K-Sync) should be procured and installed to enable interference between different sonar devices (e.g. multibeam echo sounding system, acoustic sub-bottom profiling system, acoustic Doppler current profiler, fisheries research sonar) to be minimized when they need to be operated simultaneously.
3. There were frequent dropouts in positional data from the primary GPS system, the Seapath 330. The causes of this need to be investigated.
4. At one stage during the cruise we were in a situation where neither of the zodiac boats were serviceable. One had been punctured in an encounter with the Hugin AUV while trying to recover the latter and the other sustained some structural damage during a recovery. For cruises involving projects that depend heavily on use of the zodiac boats a cost-effective way of reducing the risk to the science activities would be to carry a spare (third boat). This could be stored in an uninflated state so need not take up a lot of space.
5. A lowered ADCP is now standard instrumentation on CTD frames on many research vessels. Consideration should be given to procuring one.
6. Provision of plastic sediment plugs would improve efficiency in sampling kasten cores. Could ASC consider adding these as an option on the consumables list that is associated with the SIP?

Appendix 1. NBP19-02 event log

Peter Sheehan

Date	Time	Station	Latitude	Longitude	Description and notes
	UTC		*Degrees and decimal minutes SOUTH*	*Degrees and decimal minutes WEST*	
01 Feb	16:22	**001**	52 57.6500	73 39.0000	AUV mission 001. Trial deployment of Hugin in western Strait of Magellan
	22:15		53 03.7780	73 46.4100	Hugin recovered after mission 001
05 Feb	01:32	**002**	59 59.5498	84 52.1260	XBT 001. Deployed on transit for EM122 sound velocity profile
06 Feb	15:30	**003**	65 18.1494	92 21.6074	XBT 002. Deployed on transit for EM122 sound velocity profile
07 Feb	23:42	**004**	69 30.5220	99 47.8008	XBT 003. Deployed on transit for EM122 sound velocity profile
08 Feb	08:37	**005**	70 27.1000	101 58.1400	CTD 001
09 Feb	17:22	**006**	72 20.6100	103 45.3700	CTD 002
	19:04	**007**	72 20.6100	103 45.3700	Core 001, Kasten core
	21:13	**008**	72 20.6100	103 45.3700	Core 002, multicore. One sub-core recovered
10 Feb	04:30	**009**	73 12.7100	104 19.7000	CTD 003
	06:01	**010**	73 12.7100	104 19.7000	AUV mission 002. Deployment near Burke Island.
	07:47		73 12.6040	104 20.1850	AUV recovered after mission 002 for maintenance and re-deployment
	07:00	**011**	73 12.7100	104 19.7000	Glider mission 001. SG620 deployed near Burke Island
	09:16	**012**	73 12.7100	104 19.7000	AUV mission 003. Second deployment near Burke Island
	12:45		73 12.7100	104 19.7000	Hugin experiencing technical issues and recovered after mission 003. Burke Island deployment abandoned
	18:00		73 51.2800	103 03.9800	Arrived at Edwards Islands for seal-tagging, and GHC specimen collection and shore surveys
11 Feb	05:34	**013**	73 12.4300	104 09.2800	AUV mission 004. Hugin deployment for buoyancy test
	07:29		73 12.4300	104 09.2800	Hugin recovered after mission 004
	07:47				Departed Edwards Islands
	11:45		73 40.0000	103 15.0000	Arrived at Schaefer Islands for seal-tagging, and GHC specimen collection and shore surveys
	15:14				Departed Schaefer Islands: shore teams recalled due to poor weather. Overnight bathymetry survey in Ferrero Bay
12 Feb	11:31		73 38.9400	103 18.9900	Arrived at Schaefer Islands for seal-tagging, and GHC specimen collection and shore surveys
13 Feb	03:18	**014**	73 39.2000	103 17.0600	AUV mission 005. Hugin deployment for IH DVL test
	06:04				Hugin recovered after mission 005
	07:41	**015**	73 33.2400	103 28.0900	CTD 004

	09:36	**016**	73 33.2400	103 28.0900	Glider SG620 recovered at end of mission 001
	13:29	**017**	73 34.6000	103 11.7500	AUV mission 006. Hugin deployment near Lindsey Islands
	14:27		73 36.4300	103 04.8210	Arrived at Lindsey Islands for seal-tagging, and GHC specimen collection and shore surveys
14 Feb	02:00				Departed Lindsey Islands
	09:55	**018**	73 33.7000	103 15.5000	Hugin recovered after mission 006
	12:45	**019**	73 41.9900	103 40.1400	CTD 005
	15:21	**020**	73 46.4400	103 36.6400	CTD 006
	18:09	**021**	73 48.6600	103 32.6600	Mooring recovered from mid-shelf Pine Island Trough
	22:28	**022**	73 48.6100	106 32.7700	CTD 007
15 Feb	06:27		73 48.1300	106 35.1700	Reached mooring deployment site
	09:30	**023**	73 48.7418	106 31.9620	Mooring deployment completed
	13:52		74 08.1700	105 44.1500	Commenced medical evacuation to Rothera
17 Feb	17:42	**024**	69 11.5923	92 31.5020	XBT 004. Deployed on transit for EM122 sound velocity profile
18 Feb	04:36	**025**	68 51.1836	86 07.1436	XBT 005. Deployed on transit for EM122 sound velocity profile
19 Feb	08:01	**026**	67 57.3892	70 36.2305	XBT 006. Deployed on transit for EM122 sound velocity profile
	13:00		67 34.4100	68 08.8200	Arrived at Rothera
	16:48	**027**	67 34.4700	68 12.0400	Core 003, multicore. 11 sub-cores recovered
20 Feb	15:00	**028**			AUV mission 007. Deployment for sea floor mapping and sensor tests in Ryder Bay Hugin recovered after mission 007
21 Feb	11:00	**029**	67 34.1500	68 13.3700	CTD 008. Cast requested by Rothera
	19:24				Departed Rothera
23 Feb	17:46	**030**	70 01.6457	93 01.6864	CalTech glider SG621 recovered for Andy Thompson in Bellinsghausen Sea, southwest of Peter I Island
25 Feb	11:54	**031**	72 40.8799	108 17.2705	XBT 007. Deployed on transit for EM122 sound velocity profile. Two probes failed to initialise
	21:24	**032**	74 12.0209	105 33.9725	CTD 009
26 Feb	00:44	**033**	74 22.9376	105 04.9146	CTD 010
	02:54	**034**	74 32.1400	105 23.6330	CTD 011
	05:34	**035**	74 41.2372	105 50.4364	CTD 012
	16:35	**036**	74 56.2500	107 22.9650	Glider mission 002. Deployment of SG620 northwest of Thwaites Glacier
	17:54	**037**	74 51.6527	107 12.2603	XBT 008. Deployed on transit for EM122 sound velocity profile
27 Feb	01:30	**038**	74 56.8044	106 52.6190	CTD 013
	02:58	**039**	74 56.8044	106 52.6186	Core 004, Kasten core
	03:22	**040**	74 56.7979	106 52.6726	Core 005, multicore. One sub-core recovered
	06:04	**041**	74 56.7970	106 52.6710	Core 006, multicore. Two sub-cores recovered
	07:46	**042**	74 56.8050	106 52.6660	Core 007, jumbo gravity core (6 m)
	10:36	**043**	74 56.9800	106 53.4900	Stopped for CTD but deployment cancelled due to poor weather
	21:37	**044**	74 56.2335	107 22.9367	CTD 014
28 Feb	03:19	**045**	75 2.6650	107 7.8900	CTD 015
	04:43	**046**	75 0.6260	107 14.8980	CTD 016
	6:24	**047**	74 58.4750	107 17.7060	CTD 017
	8:27	**048**	74 56.3230	107 22.5390	Core 008, Kasten core
	13:40	**049**	74 57.7634	107 21.1006	Core 007, multi-core 007. Two sub-cores recovered

	17:39	**050**	74 57.6265	107 21.4169	Core 010, jumbo gravity core (6 m)
	22:01	**051**	75 04.2100	106 58.8900	AUV mission 008
	23:09	**052**	75 04.1418	107 00.2390	CTD 018
01 Mar	00:27	**053**	75 04.5927	107 01.8956	CTD 019
	07:33	**054**	75 05.5480	107 10.3190	CTD 020
	09:02	**055**	75 04.0297	107 11.5063	CTD 021
	10:02	**056**	75 03.4515	107 11.3150	CTD 022
	11:14	**057**	75 04.5923	107 11.0678	CTD 023
	15:33		75 05.0350	107 10.8310	Hugin recovered after mission 008
	17:18	**058**	75 04.9580	107 14.0300	CTD 024
	18:28	**059**	75 05.6383	107 09.0500	CTD 025
	21:20	**060**	75 02.2783	107 09.9550	Glider mission 003. Deployment of SG621 near Thwaites Glacier
	22:33	**061**	75 03.4079	107 13.7266	Core 011, jumbo gravity core (6 m).
02 Mar	00:25	**062**	75 03.4750	107 13.7280	Core 012, multicore. Seven sub-cores recovered
	02:50	**063**	75 01.5720	107 09.6280	Glider SG621 recovered after mission 003.
	04:57	**064**	75 02.6360	107 44.0570	CTD 026
	07:50		75 01.5495	107 30.5980	Multibeam survey in southern Thwaites area
	08:32	**065**	74 59.8390	107 30.4520	CTD 027
	15:57	**066**	74 47.6940	107 27.4310	CTD 028
	17:32	**067**	74 49.8051	107 19.3129	CTD 029
	19:03	**068**	74 52.2101	107 12.3138	CTD 030
	20:56	**069**	74 53.8953	107 01.2213	CTD 031
	22:15	**070**	74 54.9911	106 54.0189	CTD 032
	22:53		74 54.5242	106 52.3375	Multibeam mapping of northern edge of western Thwaites ice shelf
03 Mar	04:29	**071**	75 01.0432	107 51.9896	CTD 033
	05:51	**072**	75 01.4479	107 44.2337	CTD 034
	07:49	**073**	75 04.0000	107 40.0340	CTD 035
	10:20	**074**	75 02.2000	107 41.2800	CTD 036
	12:12	**075**	74 58.0640	107 31.0810	Glider SG620 recovered after mission 002.
	14:51	**076**	74 54.6820	106 57.2240	CTD 037
	15:14	**077**	74 54.6807	106 57.2011	Core 013, Kasten core
	17:16	**078**	74 54.6730	106 57.2020	Core 014, multicore. Three sub-cores recovered
	18:05		74 54.6739	106 57.2400	Multibeam survey over bathymetry gaps north of western pinning point
04 Mar	01:16	**079**	74 59.9000	106 17.4940	CTD 038
	02:42	**080**	74 57.9433	106 18.7862	CTD 039
	04:19	**081**	74 56.1010	106 39.3920	CTD 040
	06:18	**082**	74 55.9910	106 23.0760	CTD 041
	06:46	**083**	74 55.7880	106 14.8720	CTD 042
	07:53	**084**	74 55.4820	106 06.9770	CTD 043
	08:25		74 55.4823	106 06.9118	Multibeam survey in area west of eastern ice front
	12:28	**085**	74 55.0040	106 19.5877	Glider mission 004. Deployment of SG620near eastern ice shelf
	15:50		74 42.0510	105 49.3600	Seal-tagging on ice floes
05 Mar	05:52		74 49.0000	106 20.0000	Multibeam survey
	07:56		74 57.3990	106 13.5777	Begin positioning for Hugin deployment
	09:36	**086**	74 57.2374	106 15.7118	AUV mission 009. Hugin deployment
	10:25	**087**	74 53.6513	106 23.1880	CTD 044
	11:28	**088**	74 53.8090	106 24.5220	CTD 045
	12:44	**089**	74 54.1420	106 25.9250	CTD 046
	14:17	**090**	74 54.3890	106 27.0500	CTD 047
	13:00				Glider SG620 recovered after mission 004

	17:13	**091**	74 52.2840	106 19.9806	Core 015, Kasten core
	18:45	**092**	74 52.2460	106 19.9910	Core 016, multicore
	20:19	**093**	74 53.2110	106 18.9890	Core 017, jumbo gravity core
	22:06	**094**	74 53.2260	106 18.9010	Core 018, Kasten core. Core returned empty
	23:43	**095**	74 51.7790	106 20.4790	Core 019, Kasten core
06 Mar	03:45		74 53.8989	106 27.3386	Hugin recovered after mission 009
	06:57	**096**	74 59.7820	106 17.2810	Core 020, jumbo gravity core
	09:29	**097**	74 59.7900	106 17.2110	Core 021, multicore. Did not find bottom so did not trigger
	10:58	**098**	74 59.7920	106 17.2090	Core 022, multicore. Re-deployed at same location as core 021/event 097. Nine of 12 sub-cores recovered
	17:30				Multibeam survey north of previous locations
	23:33	**099**	74 36.2434	106 37.4217	CTD 048
07 Mar	00:54		74 36.2500	106 35.4000	Begin transit to Pine Island Glacier
	02:42	**100**	74 24.8108	106 01.4177	CTD 049
	07:27	**101**	74 37.9680	106 36.0350	CTD 050
	10:09	**102**	74 47.9755	104 03.0093	CTD 051
	14:14	**103**	74 50.0000	106 50.2030	CTD 052
	15:10	**104**	74 51.9868	102 04.5232	CTD 053
	17:05	**105**	74 51.6449	102 07.3636	Mooring transducer deployed at PIG-N site.
	19:10		74 52.1095	102 06.8578	Mooring recovered
	20:06	**106**	75 02.8610	102 10.7162	CTD 054
08 Mar	04:03	**107**	75 08.2560	101 43.0630	CTD 055
	06:08	**108**	74 09.4040	101 36.1970	CTD 056
	07:28	**109**	75 09.0540	101 28.1450	CTD 057
	09:02	**110**	75 07.0395	101 25.5867	CTD 058
	09:35	**111**	75 05.0110	101 20.8550	CTD 059
	10:56	**112**	75 03.7940	101 11.0810	CTD 060
	12:15	**113**	75 02.6257	101 07.8973	CTD 061
	13:34	**114**	75 01.3060	101 02.4780	CTD 062
	14:50	**115**	75 00.2197	101 56.2148	CTD 063
	16:10	**116**	74 59.1847	101 49.8898	CTD 064
	17:21	**117**	74 58.1602	101 43.1502	CTD 065
	18:28	**118**	74 56.7581	100 37.0230	CTD 066
	19:32	**119**	74 54.8561	100 32.8619	CTD 067
	20:53	**120**	74 53.0878	100 36.3016	CTD 068
	21:00		74 53.1000	100 36.3000	Multibeam survey of potential coring sites at eastern/northern Pine Island Glacier margin, then survey to PIS_S site
09 Mar	05:50	**121**	75 02.6555	102 12.1266	Mooring re-deployment close to PIG_S site begins
	09:58		75 03.0461	102 09.3033	Mooring re-deployed complete
	10:52		75 03.0461	102 10.5807	Transducer deployment following mooring re-deployment
	12:04	**122**	750 3.4222	102 10.4604	CTD 069
	16:07	**123**	75 54.5410	102 42.8840	CTD 070
	18:36	**124**	75 00.0220	102 44.2502	CTD 071
	19:12	**125**	75 02.4849	102 44.0048	CTD 072
	20:23	**126**	75 04.5035	102 43.9856	CTD 073
	21:53	**127**	75 05.4877	102 43.9989	CTD 074
	22:23	**128**	75 06.4934	102 44.0080	CTD 075
10 Mar	02:12	**129**	75 04.2293	104 13.6821	CTD 076
	03:09	**130**	75 04.2494	104 13.7064	Core 023, Kasten core
	04:41	**131**	75 04.2650	104 13.7130	Core 024, jumbo gravity core (6m)

	08:09	**132**	75 02.3085	103 40.5784	Core 025, jumbo gravity core (6m)
	10:33	**133**	75 02.2540	103 41.0040	Core 026, multicore
	14:20	**134**	74 58.5100	104 09.5270	CTD 077
	17:26	**135**	74 49.3094	104 30.7919	CTD 078
	19:48	**136**	74 43.3713	104 39.4638	CTD 079
	22:17	**137**	74 40.4420	104 54.8767	CTD 080
11 Mar	00:39	**138**	74 37.7234	104 53.1459	CTD 081
	05:58	**139**	74 19.9880	103 09.9130	CTD 082
	06:26	**140**	74 18.1850	103 16.6020	CTD 083
	08:04	**141**	74 14.9995	103 32.0004	CTD 084
	09:26	**142**	74 12.9089	103 41.7966	CTD 085
	11:15	**143**	74 06.3094	103 48.4309	CTD 086
	13:57	**144**	74 00.1900	103 05.6012	CTD 087
	14:45				Transit to Edwards Islands
	16:30				Arrived at Edwards Islands for seal-tagging, and GHC specimen collection and shore surveys.
	21:05	**145**	73 42.9996	103 50.7793	CTD 088
	23:33	**146**	73 43.9910	103 28.5700	CTD 089
12 Mar	02:33		74 01.5472	202 55.0539	Underway after recovery of shore teams
	03:35	**147**	74 01.5520	102 55.0570	CTD 090
	04:20				Multibeam survey south of Canisteo Peninsula
	11:03	**148**	74 00.5180	102 37.3750	CTD 091
	12:08	**149**	74 00.9880	103 39.8560	CTD 092
	13:08	**150**	74 00.6110	102 46.8500	CTD 093
	14:58	**151**	73 59.9920	102 52.3490	CTD 094
	15:39	**152**	74 01.6054	102 54.9673	Core 027, Kasten core
	17:05	**153**	74 01.5930	102 55.0040	Core 028, box core
	19:26	**154**	73 57.5574	103 03.9560	CTD 095
	23:57	**155**	73 42.2548	104 13.4610	CTD 096
13 Mar	12:00				Abandoning plans for work in Ferrero Bay. Beginning return transit to Punta Arenas
14 Mar	20:15	**156**	71 01.6671	107 07.8928	CTD 097
	22:17	**157**	71 04.8601	106 59.4452	CTD 098
	23:40	**158**	71 04.1583	107 00.9055	CTD 099
15 Mar	01:06	**159**	71 03.5360	107 00.8680	CTD 100
	04:07	**160**	71 02.3044	107 01.5353	CTD 101
	05:43	**161**	71 01.5092	107 00.2760	CTD 102
	07:33	**162**	71 00.2687	106 58.7242	CTD 103
	09:44	**163**	70 58.4024	106 59.4608	CTD 104
16 Mar	00:25	**164**	70 27.1408	101 58.0682	CTD 105
17 Mar	18:30		69 51.9223	83 33.8695	Beginning search for glider SG539 (for Andy Thompson at CalTech)
18 Mar	12:54	**165**	70 01.8864	84 28.2413	CTD 106
	13:54	**166**	69 59.0094	84 30.0522	CTD 107
	15:10	**167**	69 56.7380	84 26.5260	CTD 108
	16:28	**168**	69 55.3546	84 28.1342	CTD 109
	17:55	**169**	69 53.6810	84 27.7441	CTD 110
	19:24	**170**	69 51.8150	84 27.2500	CTD 111
	22:06	**171**	69 48.2158	84 26.7416	CTD 112
19 Mar	01:02	**172**	69 40.9610	84 23.5640	CTD 113. Abandoning search for glider SG539
	10:00		68 57.0000	87 10.0000	Multibeam survey over lower Belgica Fan
	15:00				Re-commencing transit to Punta Arenas
20 Mar	22:40	**173**	64 33.8628	76 59.8965	XBT09. Deployed on transit for SVP
24 Mar	20:00				NBP tied up at Muelle Prat, Punta Arenas

Appendix 2. Coring Station Table

Rachel Clark

BC: Box Corer, KC: Kasten Corer, JPC: Jumbo Gravity Core, MC: Multicorer; CC: Core catcher

Gear	Core Number	Station	Date	Start (UTC)	At Seafloor (UTC)	On Deck (UTC)	Location	Latitude (deg/min)	Longitude (deg/min)	Water depth (m)	Recovery (m)
KC	01	007	09FEB2019	19:04	19:27	20:01	Demas Ice Tongue	72 20.606	103 45.355	666	1.41 + 0.19 (CC)
MC	02	008	09FEB2019	21:13	21:37	22:05	Demas Ice Tongue	72 20.602	103 45.375	665	0.070
MC	03	027	19FEB2019	16:48	17:07	17:29	Ryder Bay	67 34.467	68 12.044	504	0.380
KC	04	039	27FEB2019	2:19	2:37	3:02	Thwaites W. Ice Shelf	74 56.804	106 52.619	469	2.515 + 0.19 (CC)
MC	05	040	27FEB2019	3:22	3:46	4:11	Thwaites W. Ice Shelf	74 56.798	106 52.673	466	0.000
MC	06	041	27FEB2019	6:04	6:27	6:47	Thwaites W. Ice Shelf	74 56.797	106 52.671	467	0.360
JPC	07	042	27FEB2019	7:46	8:05	8:30	Northern Thwaites W. Ice Shelf	74 56.805	106 52.666	467	1.450
KC	08	048	28FEB2019	8:24	9:07	10:00	Thwaites W. Ice Shelf	74 56.323	107 22.539	1186	2.82 + 0.19 (CC)
MC	09	049	28FEB2019	13:29	14:40	15:27	Thwaites W. Ice Shelf	74 57.763	107 21.101	1138	0.380
JPC	10	050	28FEB2019	17:39	18:19	18:52	Thwaites W. Ice Shelf	74 57.627	107 21.417	1166	4.105

JPC	11	061	01MAR2019	22:33	22:59	23:31	Thwaites W. Ice Shelf	75 03.475	107 13.727	752	2.645
MC	12	062	02MAR2019	0:25	1:02	1:37	Thwaites W. Ice Shelf	75 03.475	107 13.728	748	0.380
KC	13	077	03MAR2019	15:14	15:36	15:57	Thwaites W. pinning Point	74 54.6807	106 57.2011	463	2.79 + 0.19 (CC)
MC	14	078	03MAR2019	16:33	16:57	17:18	Thwaites W. pinning point	74 54.673	106 57.202	467	0.36
KC	15	091	05MAR2019	17:14	17:33	17:56	Thwaites middle embayment	74 52.2840	106 19.9806	545	2.92 + 0.19 (CC)
MC	16	092	05MAR2019	18:45	19:08	19:33	Thwaites middle embayment	74 52.246	106 19.991	549	0.400
JPC	17	093	05MAR2019	20:25	20:43	21:09	Thwaites middle embayment	74 53.211	106 18.989	507	1.29
KC	18	094	05MAR2019	22:06	22:25	22:47	Thwaites middle embayment	74 53.226	106 18.901	508	0.000
KC	19	095	05MAR2019	23:43	0:09	0:39	Thwaites middle embayment	74 51.779	106 20.479	704	2.92 + 0.19 (CC)
JPC	20	096	06MAR2019	7:09	7:38	8:10	Thwaites middle deep trough	74 59.782	106 17.281	1029	4.155
MC	21	097	06MAR2019	9:29	10:15	10:55	Thwaites middle deep trough	74 59.790	106 17.211	1021	0.00

MC	22	098	06MAR2019	10:58	11:50	12:34	Thwaites middle deep trough	74 59.792	106 17.209	1022	0.47
KC	23	130	10MAR2019	3:11	3:35	4:02	Thwaites E. ice shelf corner	75 04.2494	104 13.7064	677	2.12 + 0.19 (CC)
JPC	24	131	10MAR2019	4:41	5:03	5:36	Thwaites E. ice shelf corner	75 04.265	104 13.713	676	2.49
JPC	25	132	10MAR2019	8:09	8:30	9:01	Thwaites E. ice shelf corner	75 02.3085	103 40.5784	558	6.13
MC	26	133	10MAR2019	10:33	11:02	11:30	Thwaites E. ice shelf corner	75 02.254	103 41.004	557	0.42
KC	27	152	12MAR2019	15:39	16:02	16:35	South of Canisteo Peninsula	74 01.605	102 54.967	644	2.72 + 0.19 (CC)
BC	28	153	12MAR2019	17:05	17:35	18:08	South of Canisteo Peninsula	74 01.593	102 55.004	645	0.17

Appendix 3. Kasten core descriptions and sub-bottom profiles across sites

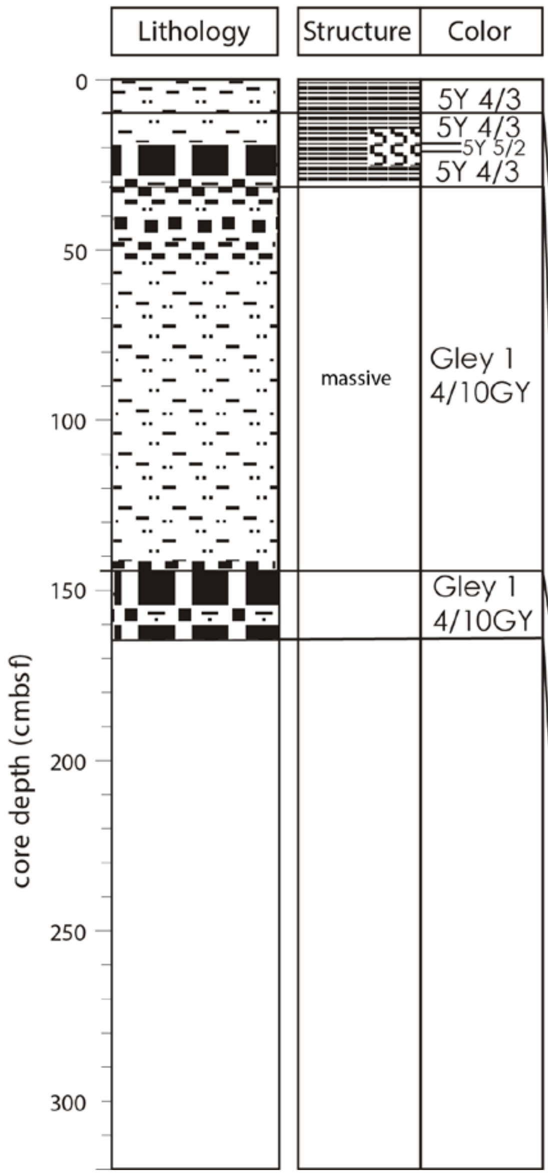
Rebecca Totten Minzoni

All lithological descriptions were conducted by Dr. Totten Minzoni; descriptions on the following pages are based on sediment color (Munsell Color Chart), texture, fossil content, and sedimentary structures. Core disturbance is noted where present.

On the pages following the core descriptions are figures showing Knudsen acoustic sub-bottom profiles across the cores sites, which were produced by Dr Kelly Hogan.

KC-01 | Abbott Ice Shelf/ Demas Ice Tongue | NBP19-02

Recovery: 1.66 m | 72° 20.606′ S, 103°45.355′ W | Water depth: 666 m



Description

Unit 4: 0- 10 cmbsf:
Tan orange-brown sandy silty mud with faint laminations and diverse benthic fauna (including foraminifera). Up to 8 mm diameter pebbles of mafic composition. Good recovery of sea floor.

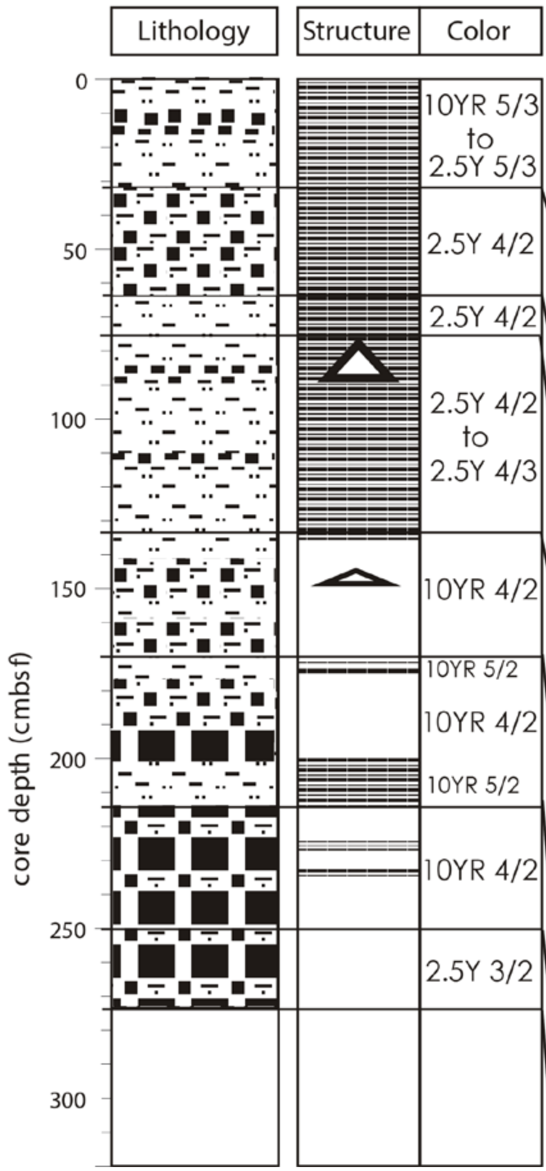
Unit 3: 10- 30 cmbsf:
Dark tan-orange brown sandy mud with laminations and abundant pebbles. Pebble rich layer 18-21 cmbsf. Burrow at 23 cmbsf.
Pebbles at 27 to 33 cmbsf. Color change at base (increasing orange/oxidation up-section).

Unit 2: 30-143 cmbsf:
Olive grey silty sandy mud with abundant pebbles throughout. Pebble-rich layer at 49-52 cmbsf. Large ~5 cm diameter pebble 80 to 82 cmbsf. Fewer pebbles (silty mud with sparse sand) from 90 to 70 cmbsf.

Unit 1/Core Catcher: 143-166 cmbsf:
Dark olive grey pebbly sandy mud with up to 6 cm pebbles and fine to xse sand of varied lithology. Barren of fossils. Granitic and mafic clasts up to 4 cm diameter.

KC-04 | NW Thwaites Glacier Ice Shelf | NBP19-02

Recovery: 2.725 m | 74° 56.80′ S, 106°52.67′ W | Water depth: 483 m



Description

Unit 7: 0- 32 cmbsf:
Light olive brown to brown mud. Sparse gravel. Sandy interval from 7 to 14 cmbsf with slightly olive color. Very wet and soupy. More orange in color indicating oxygenation, good preservation of seafloor. Forams.

Unit 6: 32- 63 cmbsf:
Dark greyish brown laminated sandy mud with dark vfL to crsL sand and subangular gravel. Wet. Visible lamination. Forams.

Unit 5: 63- 76 cmbsf:
Dark greyish brown sandy mud with sparse gravel. Wet. Laminated. Forams.

Unit 4: 76- 135 cmbsf:
Dark greyish brown sandy mud with gravel-rich layers, containing 2 to 3 cm diameter subrounded gravel. Layer from 90 to 76 cmbsf may be graded. Forams.

Unit 3: 135- 170 cmbsf:
Alternating sandy gravelly mud and lesser mud-rich sparse gravel beds that are ~3 cm thick. Subangular clasts of mixed lithology. Sand size is vfU-crsL. Grades upsection.

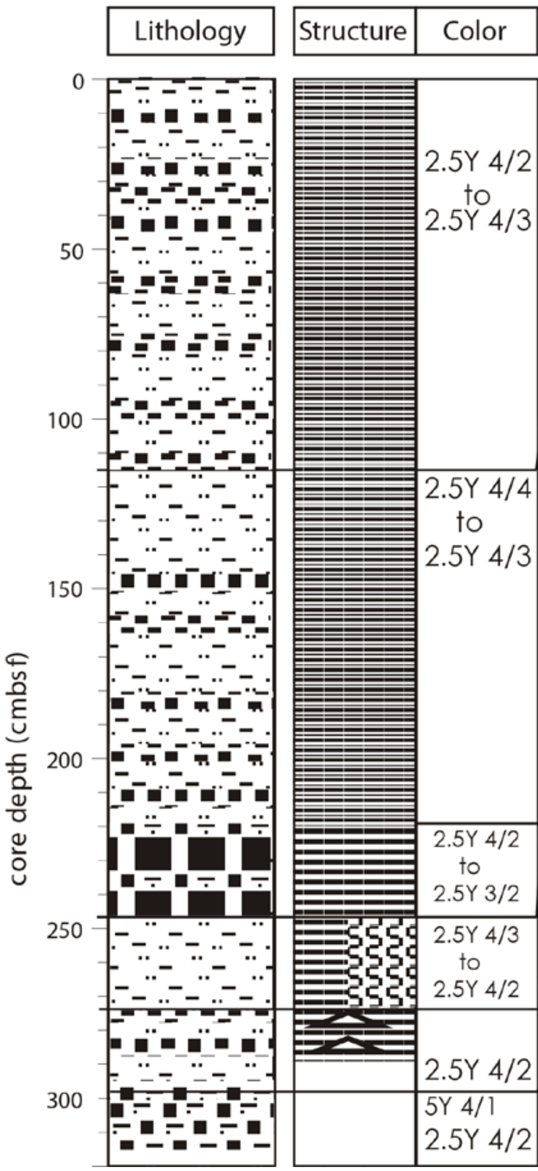
Unit 2: 170- 215 cmbsf:
Dark greyish brown gravelly sandy mud with vfL to crsL sand and gravel. Subangular grains of mixed lithology. May grade upsection. Dark greyish brown clay with sparse sand layers at 170- 174 and 201- 215 cmbsf.

Unit 1: 215- 251.5 cmbsf:
Dark greyish brown gravelly sandy mud with fL to mL subangular sand of variable lithology. Massive, stiff with ~1 cm thick clay layer at 220 cmbsf.

Core Catcher: 251.5- 272.5 cmbsf:
Full core catcher (21 cm) of very dark greyish brown sandy silty clay. Stiff, with gravel.

KC-08 Thwaites Glacier Deep Western Trough NBP19-02

Recovery: 3.16 m 74° 56.323′ S, 107°22.539′ W Water depth: 1186 m



Description

Unit 4: 0- 114 cmbsf:
Dark greyish brown to olive brown silty clay with vfL sand throughout and <1 cm thick fL-mL sand laminations every ~2.5 cm. Sand lenses are darker in color, likely due to dark mafic or coal sand clasts (2.5Y 4/2 to 3/2). Upper 40 cm is very soupy wet silty clay.

Unit 3: 114- 246 cmbsf:
Olive brown silty clay with sandy ~0.2 to 2.0 cm thick sandy laminations and gravelly sandy mud at base (fU to crsU sand; 2.5Y 4/2 to 3/2 v. dark greyish brown).

The sand laminations are dark, with vfU to fU subrounded to subangular sand, with dark clasts of mafic or coal composition.

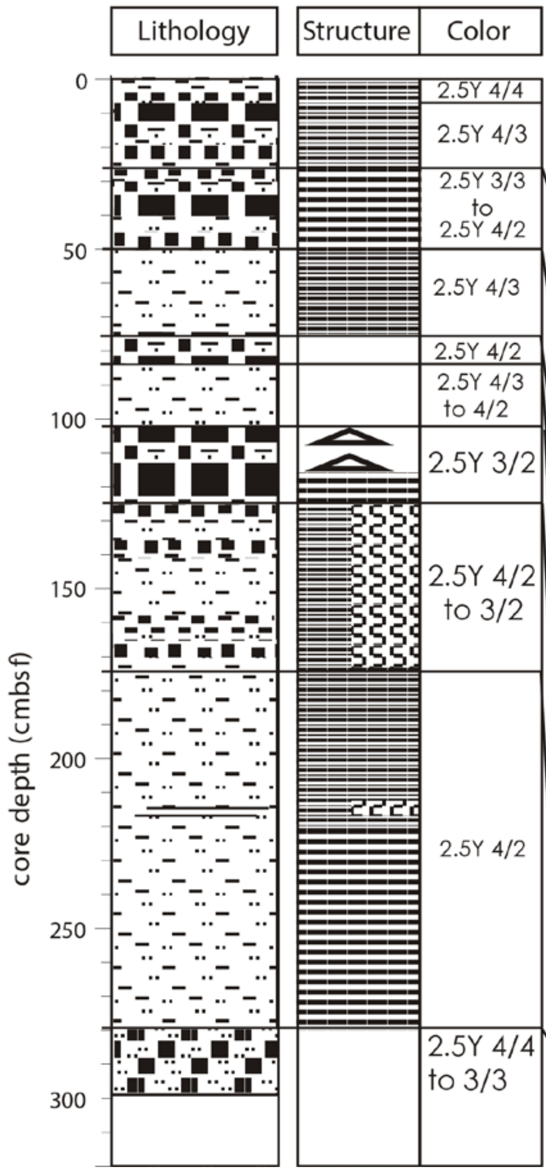
Unit 2: 246- 273 cmbsf:
Mottled light greyish brown to dark greyish brown silty clay with sparse vfL to fL sand. Putative burrows at 250 to 253 cmbsf. Dark black fine sand lense at 269.5 cmbsf. Wet, soft pudding texture.

Unit 1: 273-297 cmbsf:
Dark greyish brown clay with vfU to fU sand at base (290-297 cmbsf) and vfU sand layers at 284- 289 cmbsf and 273-274 cmbsf. Finer layers at 275 and 276.5 cmbnsf.

Core Catcher: 297- 316 cmbsf:
Full core catcher (19 cm) of greyish brown to dark grey silty sandy clay. Soft, no gravel.

KC-13 | Thwaites Glacier Deep Western Trough | NBP19-02

Recovery: 2.98 m | 74° 54.6807′ S, 106°57.2011′ W | Water depth: 463 m



Description

Unit 8: 0- 25 cmbsf:
Olive brown silty clay with vfL snad throughout and faint laminations of vfL to fU sand of darker color. Benthic forams in upper 2 cm.

Unit 7: 25- 49.5 cmbsf:
Dark olive brown to dark greyish brown sandy silty clay with interbedded olive brown silty clay with gravel. Grey lense at 30-32 cm.

Unit 6: 49.5- 74.5 cmbsf:
Olive brown silty clay with sparse vfL sand of mafic composition. Faint laminations.

Unit 5: 74.5- 83 cmbsf:
Dark olive brown sandy silty clay- graded ~1-3 cm beds, interbedded with dark greyish brown silty clay.

Unit 4: 83- 103 cmbsf:
olive brown silty clay (no sand). Massive.

Unit 3: 103- 124 cmbsf:
Dark olive brown sandy silty with common 1- 2 cm diametersubrounded gravel of mafic composition.

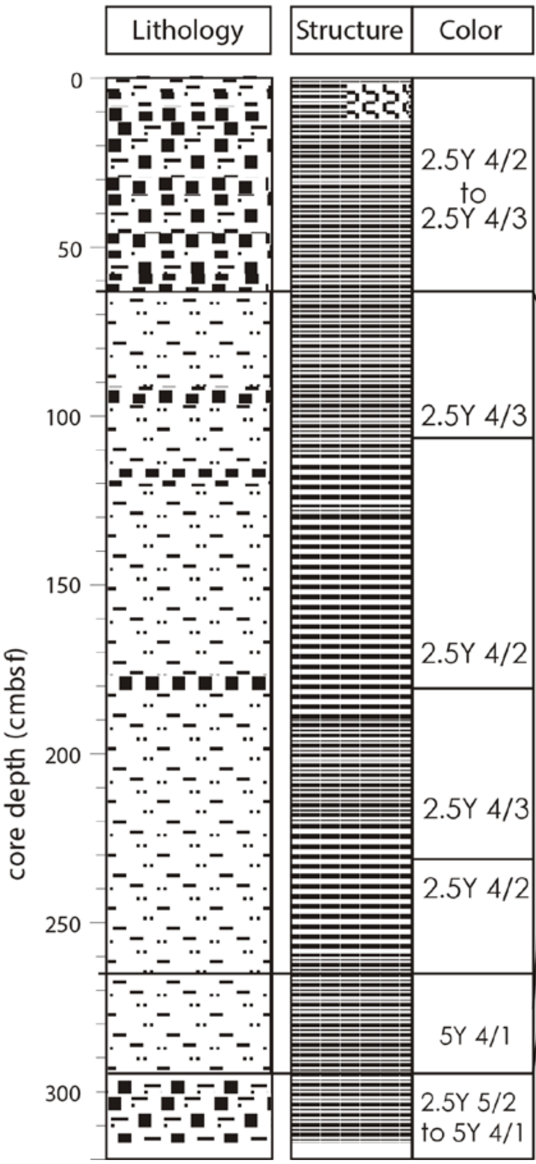
Unit 2: 124- 184 cmbsf:
silty clay with sparse vfL-vfU sand and crsU sand filled burrows. Burrows extend 10-15 cm vertically and appear to branch (130-141 cmbsf). Some burrows appear to be infilled from Unit 3.

Unit 1: 184- 279 cmbsf:
Dark greyish brown silty clay with sparse vfL to vfU sand. Weakly laminated.

Core Catcher: 279- 298 cmbsf:
Full core catcher (19 cm) of olive brown to dark olive brown sandy silty clay with vfL-mL subrounded sand.

KC-15 W side of Thwaites Eastern Ice Shelf (shallow basin) NBP19-02

Recovery: 3.15 m 74° 52.2840′ S, 106°19.9806′ W Water depth: 545 m



Description

Unit 3: 0- 62 cmbsf:

Olive brown sandy silty clay with vfL and of mafic (dark) composition; with 0.3 to 1.7 cm thick vfL-mL subrounded to rounded quartz-rich sand laminations and beds. Some mottling and burrows (sand-filled) at base of unit and likely in the top where laminations thicken or have a lense-shape. Black lams at 42 cmbsf.

Unit 2: 62- 264 cmbsf:

Dark greyish brown to olive brown silty clay with vfL to fL subrounded quartz-rich sand. Dark mafic sand (or coal clasts?) form laminations.
119 cmbsf: 0.2 cm thick vfL-fU angular to subrounded sand bed of mixed lithology, including quartz and dark (mafic or coal) composition.
156- 161 cmbsf: dark laminations
179 cmbsf: 0.2 cm thick sandy clay lamination
200-250 cmbsf: laminations of varied colors

Unit 1: 264- 296 cmbsf:

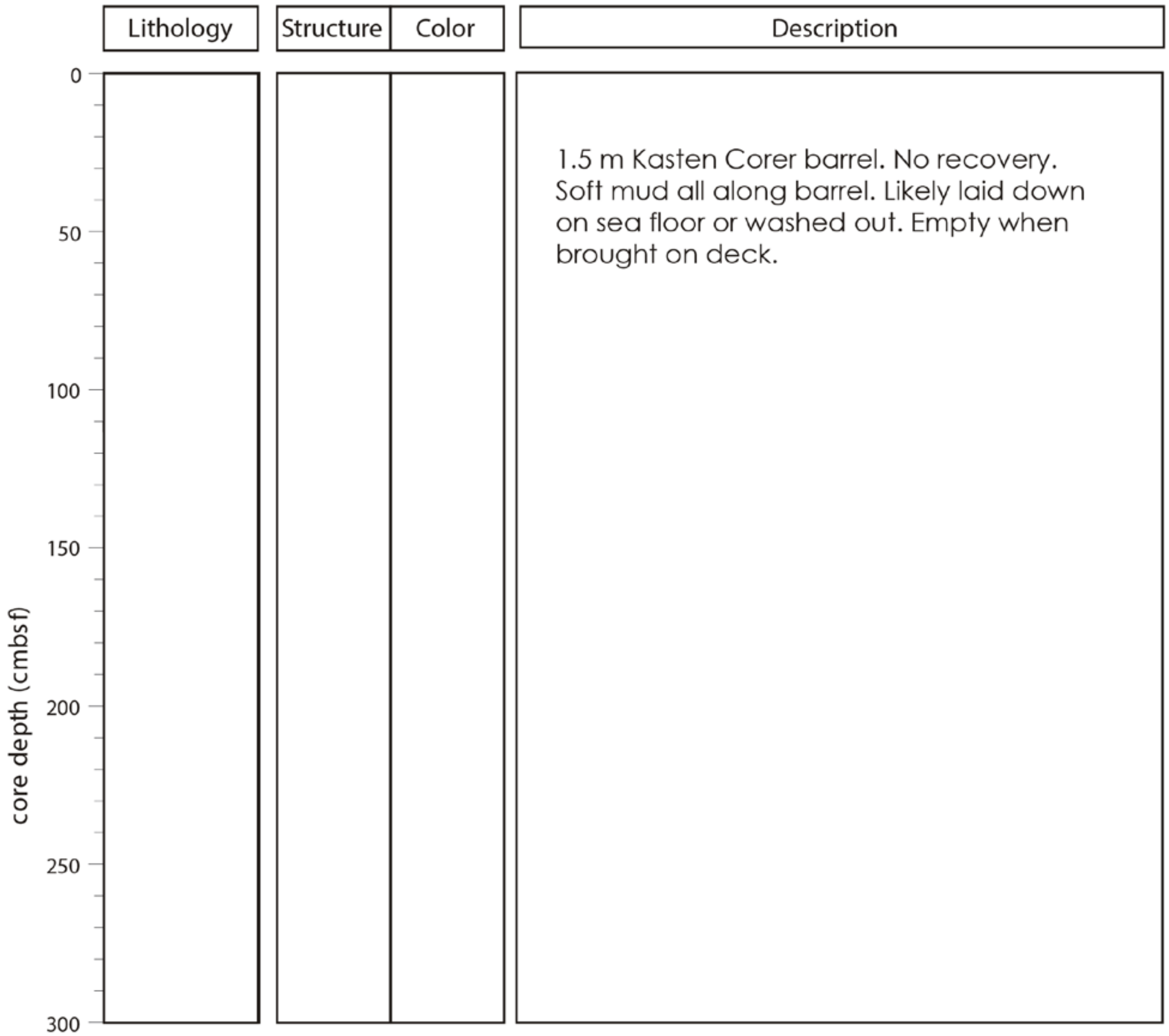
Dark grey silty clay with sparse vfL to vfU sand. Faint grey laminations at 280.5 and 277 cmbsf. Olive brown ~0,1 cm thick laminations from 264 to 272 cmbsf. Gradational contact with Unit 2.

Core Catcher: 296- 315 cmbsf:

Full core catcher (19 cm) of greyish brown to dark grey silty sandy clay. Soft, no gravel.

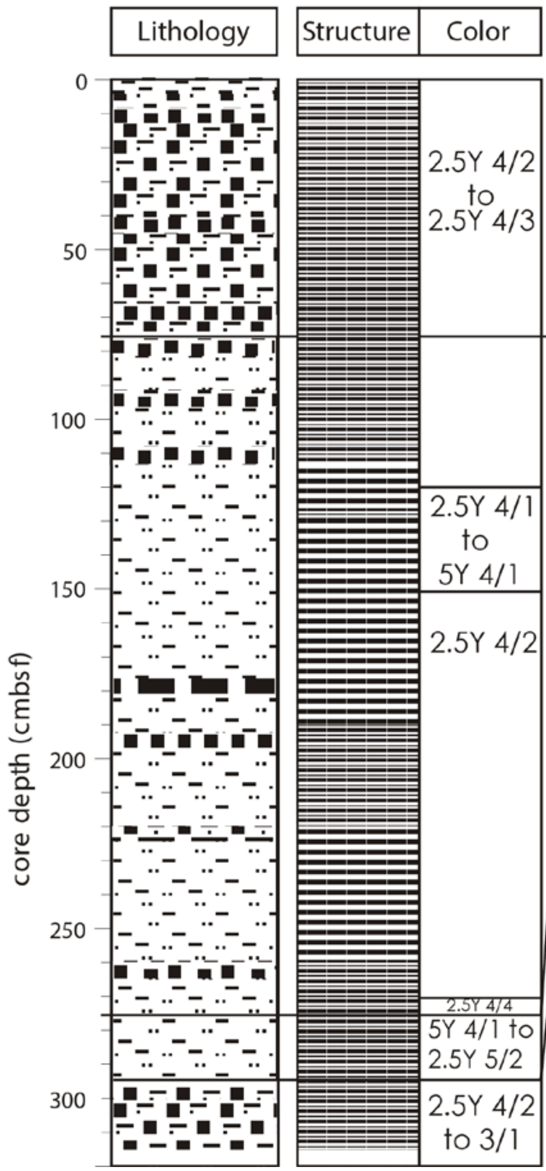
KC-18 W side of Thwaites Eastern Ice Shelf (plateau) NBP19-02

Recovery: 0 m 74° 53.226′ S, 106°18.901´ W Water depth: 508 m



KC-19 W side of Thwaites Eastern Ice Shelf (semi-deep basin) NBP19-02

Recovery: 3.165 m 74° 51.779′ S, 106°20.479′ W Water depth: 704m



Description

Unit 3: 0- 75 cmbsf:

Dark greyish brown grading to dark olive brown sandy silty clay with 0.2 to 2 cm thick sand laminations throughout of 2.5Y 3/2 and 2.5Y 4/3 vfL-fU sand of mafic and quartz composition. (The sand laminations create dark grey to light olive brown "stripes".)

Unit 2: 75- 275 cmbsf:

Dark greyish brown silty clay with sparse vfL-vfU sand and dark laminations at 187, 115-117, 173-175 cmbsf. Dark laminations have orange-brown laminations overlying them and underlying them. 173-175 cmbsf may be mottled. Dark coloration from dark sand grains(eimafic and/or coal clasts). Sparse to absent gravel; two ~2 cm diameter felsic pebbles @ 179-180 cm and 222cmmbsf.

Unit 1: 275- 297.5 cmbsf:

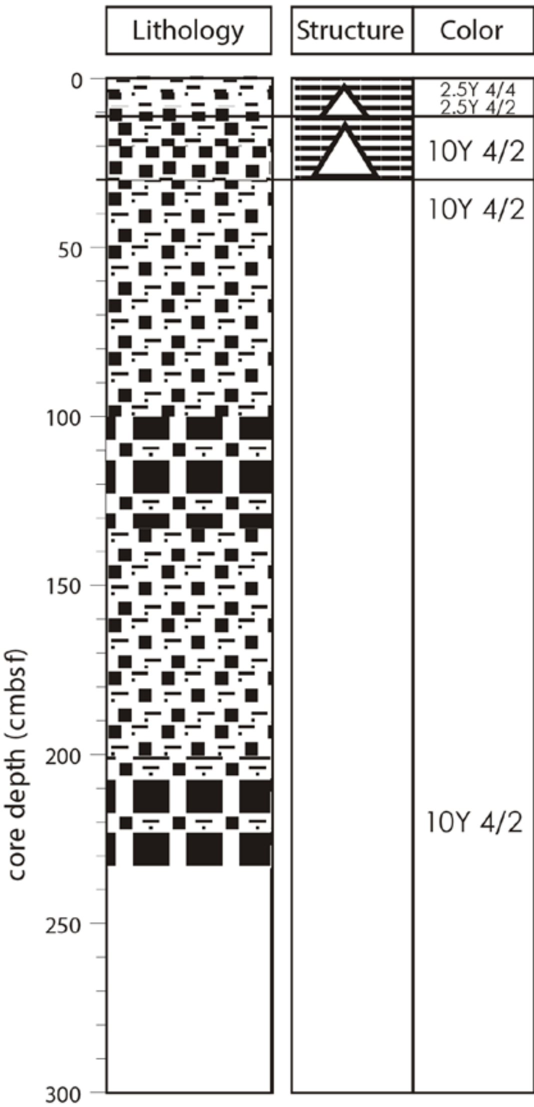
Dark grey to greyish brown silty clay with sparse vfL to vfU sand and olive brown ~0,1 cm thick laminations.

Core Catcher: 297.5- 316.5 cmbsf:

Full core catcher (19 cm) of greyish brown silty sandy clay with olive brown faint coloration that may be laminations.

KC-23 Thwaites Eastern Ice Shelf 'southeast corner' NBP19-02

Recovery: 2.325m 75° 04.2494′ S, 104°13.7064′ W Water depth: 677 m



Description

Unit 3: 0- 11 cmbsf:
Dark greyish brown grading to olive brown sandy silty clay with black organic-rich mottles and vfL-fU sand.
Top: Live benthic foraminifera, pelecypods
7-12 cmbsf: graded fL-crsU sand bed with scour base

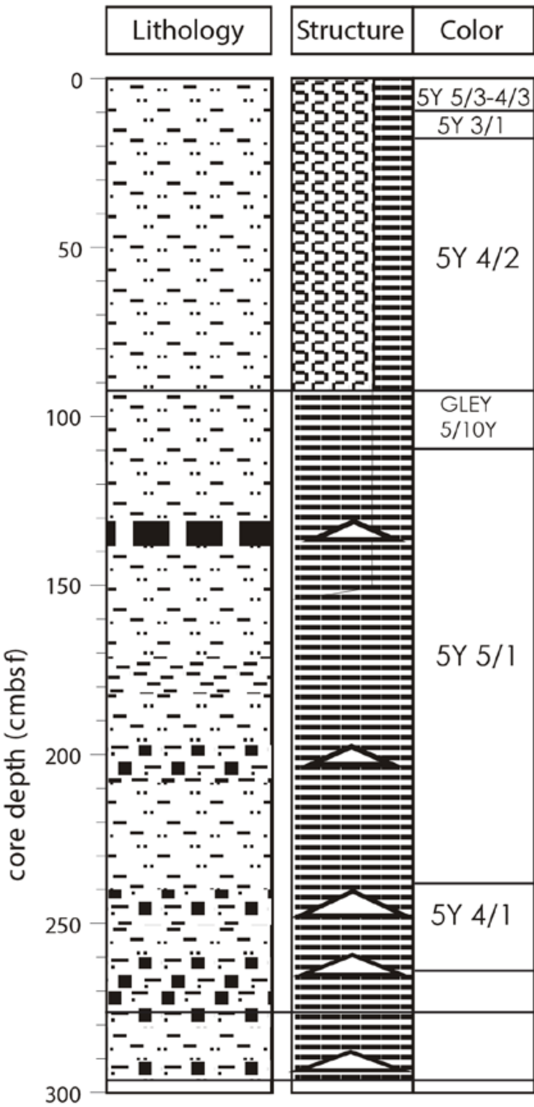
Unit 2: 11- 30 cmbsf:
Sandy silty clay with graded crsU to fU sand beds

Unit 1: 30- 213.5 cmbsf:
Greyish brown clayey silty sand with common gravel up to 5 cm diameter and angular to subangular clasts of mafic and felsic comp. and sedimentary clasts. Sand dominat mode of wide range: vfL to crsU sand of similarly varied composition, with abundant quartz. Dark clasts may include coal.
152 cmbsf: large ~5 cm diameter clast
200-206 cmbsf: large dark green ~7 cm diameter clast

Core Catcher:
Full core catcher (19 cm) but cutter nose fell out on deck and was bagged. Similiar to Unit 1; abundant gravel.

KC-27 | Cranton Bay (South of Canisteo Pen.) | NBP19-02

Recovery: 2.97 m | 74° 01.6054′ S, 102°54.9673′ W | Water depth: 644 m



Description

Unit 2: 0- 96 cmbsf:

Olive grey to green silty clay with sparse vfL sand, abundant sponge spicules, diatoms, and large benthic foraminifera. Black organic-rich intervals @5-7cm and 11-15 cm (discontinuous).

0-5 cm: soupy green surgace

5-7 cm: vfL-nL sand abundant

12-32 cm, 36-40 cm: songe spicules in life position

30-37 cm: burrows

Unit 1: 96-297 cmbsf:

Greenish grey to grey sandy silty clay with sand beds, most of which are normal graded beds (crsU sand to vfL sand to sandy clay). Water extrudes from sand beds. Color gradation from Unit 1 to Unit 2 from 106 to 92 cmbsf, where color changes from gray to bright green olive gray.

132-134 and 136 to 140 cmbsf: clasts of 1.5 cm diameter

171-172 cmbsf: cream olive grey bed

170-180cmbsf: organic-rich mottles

241-250 cmbsf: crsU sand and gravel to fU sand graded bed; diverse lithology

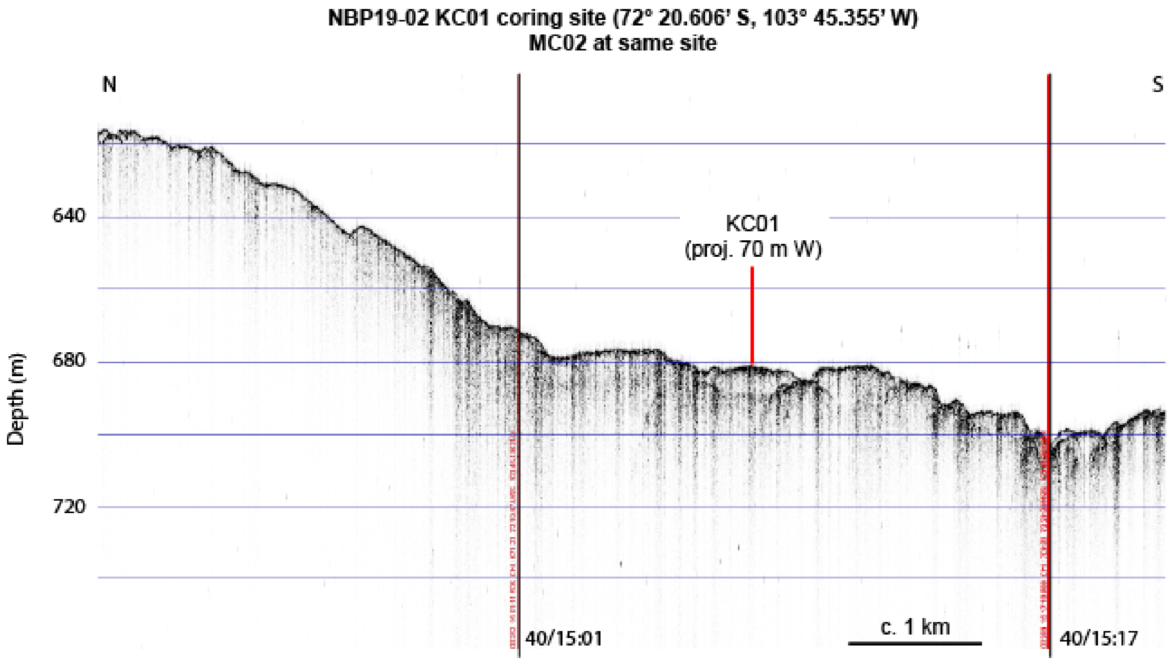
264-256 cmbsf: graded bed of crsU to fU sand (no clay)

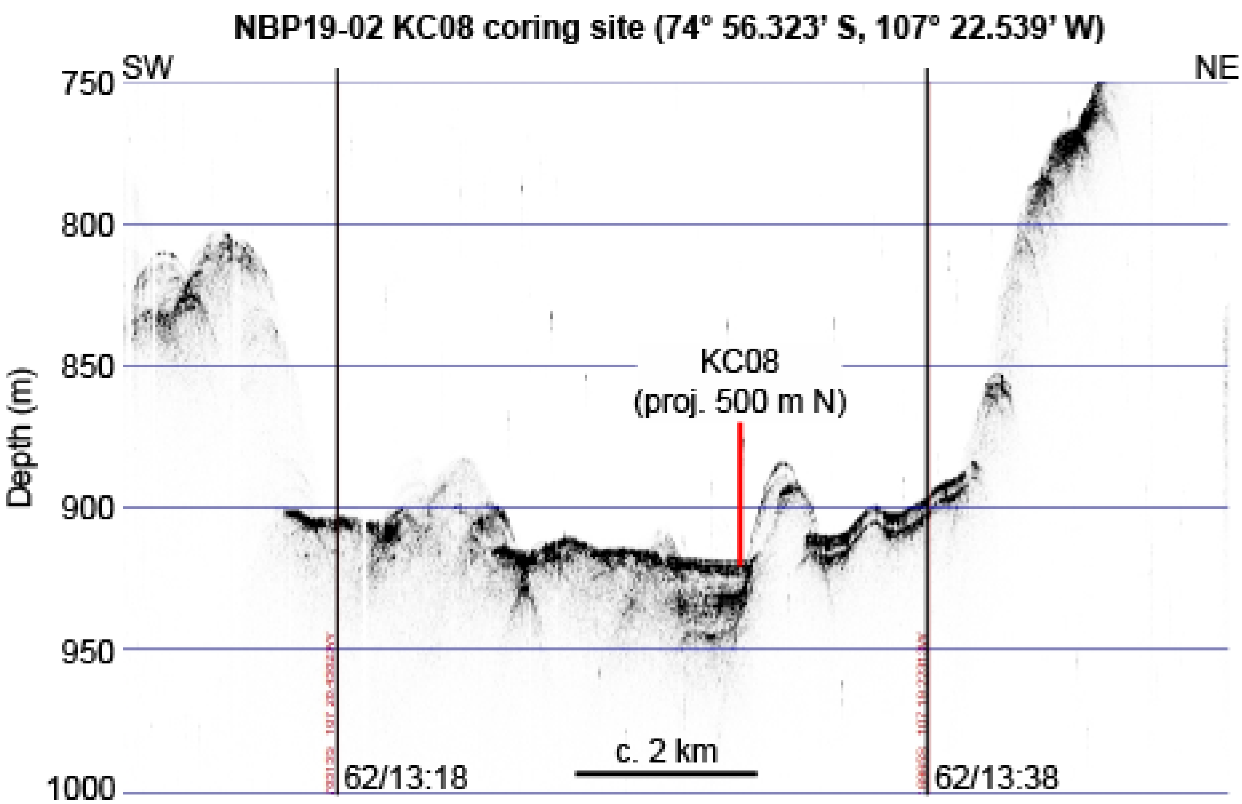
294-289 cmbsf: graded bed of vfL to fU sand

Deformation noted at 130 cm, 250 cm, and 270 cmbsf.

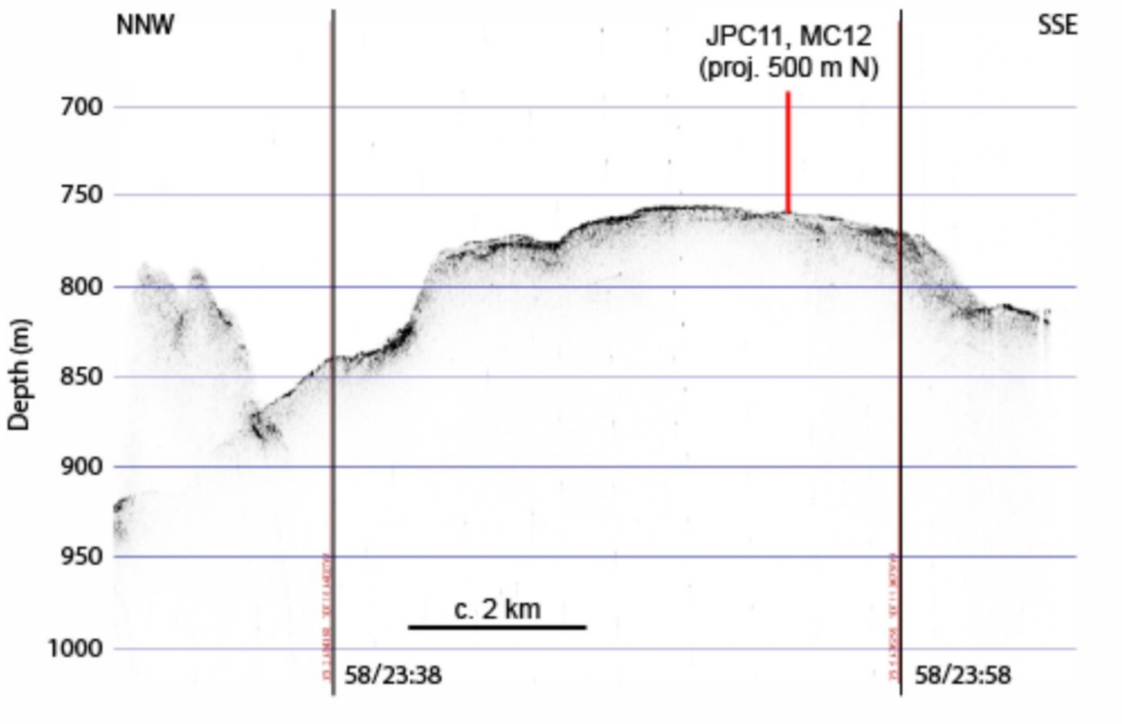
Core Catcher (277-297 cmbsf):

full core catcher (20 cm), part of Unit 1

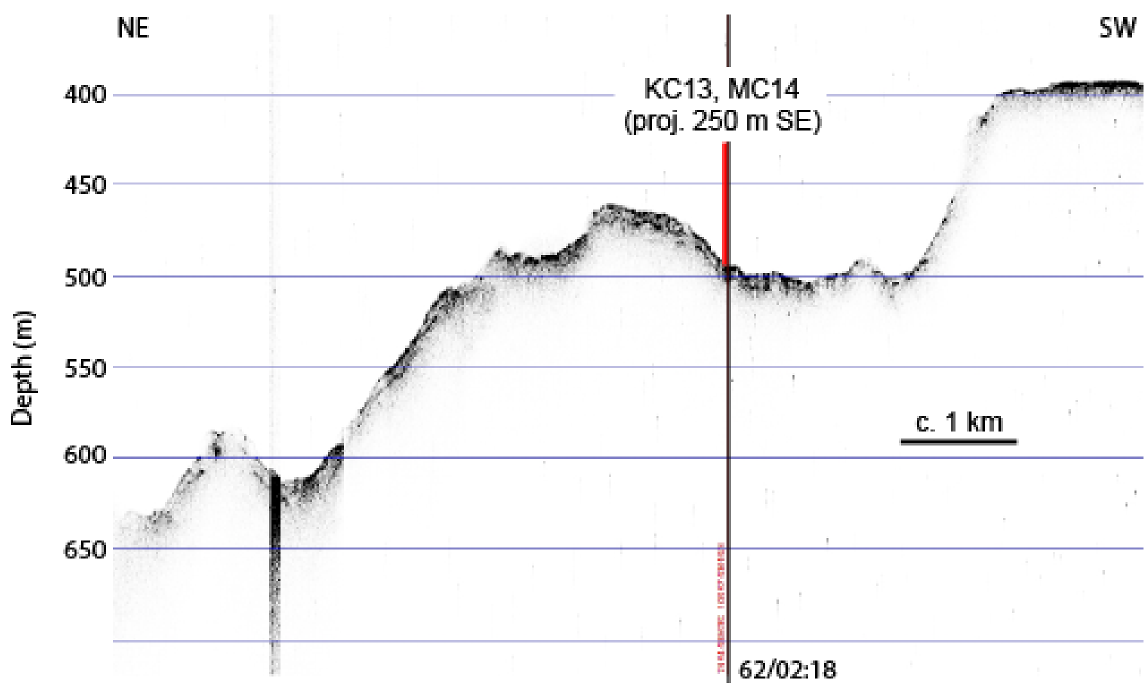

NBP19-02 KC01 coring site (72° 20.606' S, 103° 45.355' W)
MC02 at same site
N
S
640
680
720
Depth (m)
KC01
(proj. 70 m W)
40/15:01
c. 1 km
40/15:17

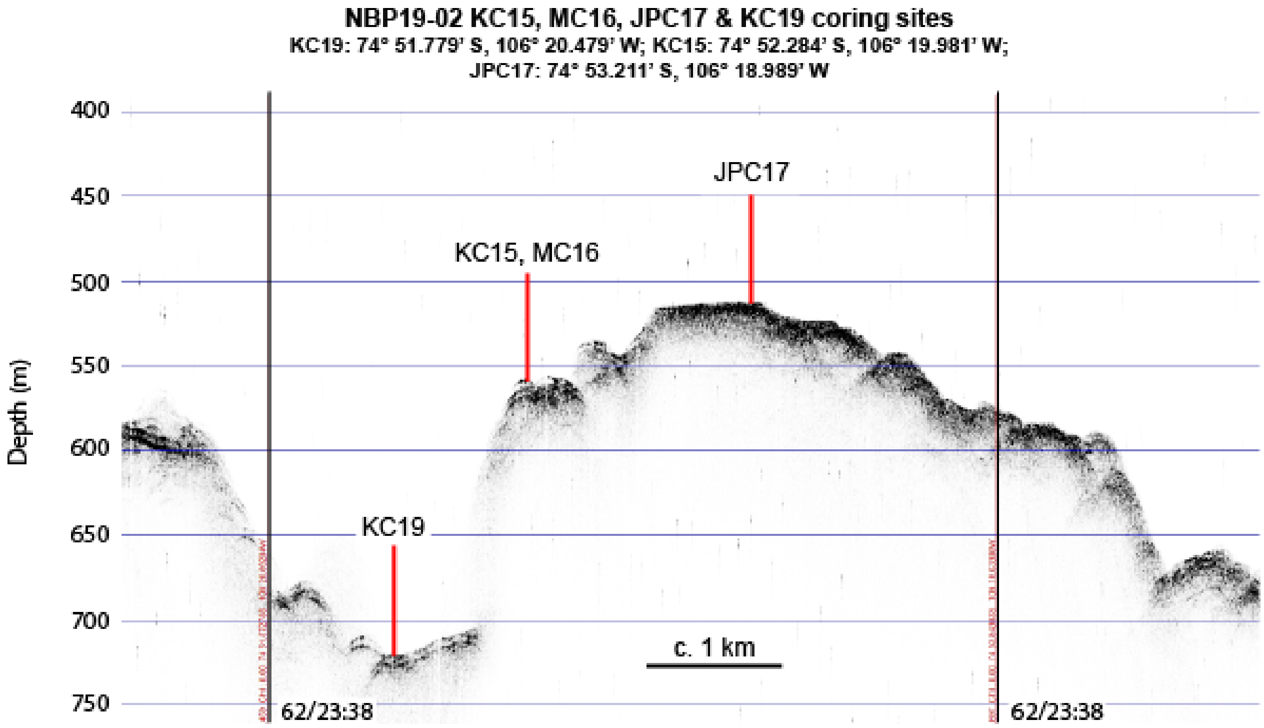

NBP19-02 KC08 coring site (74° 56.323' S, 107° 22.539' W)
SW
NE
750
800
850
900
950
1000
Depth (m)
KC08
(proj. 500 m N)
62/13:18
c. 2 km
62/13:38

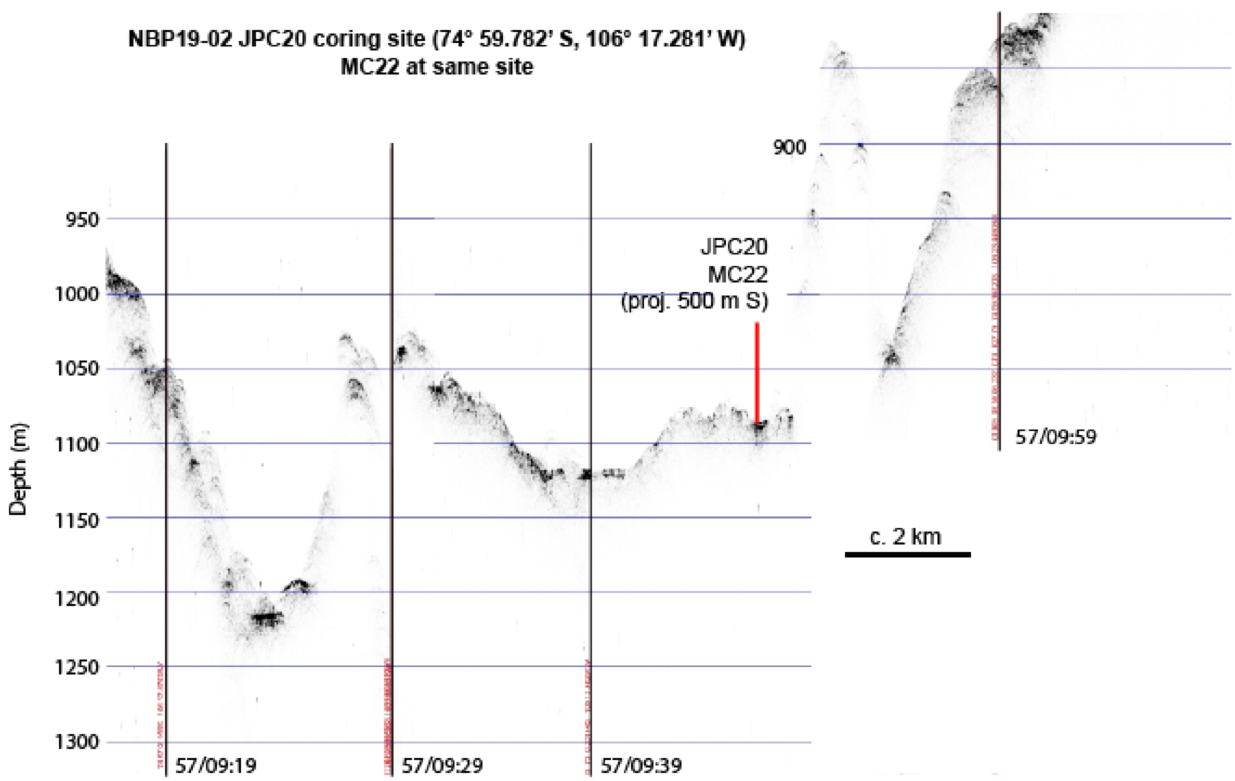
NBP19-02 JPC11 & MC12 coring site (75° 03.475' S, 107° 13.727' W)



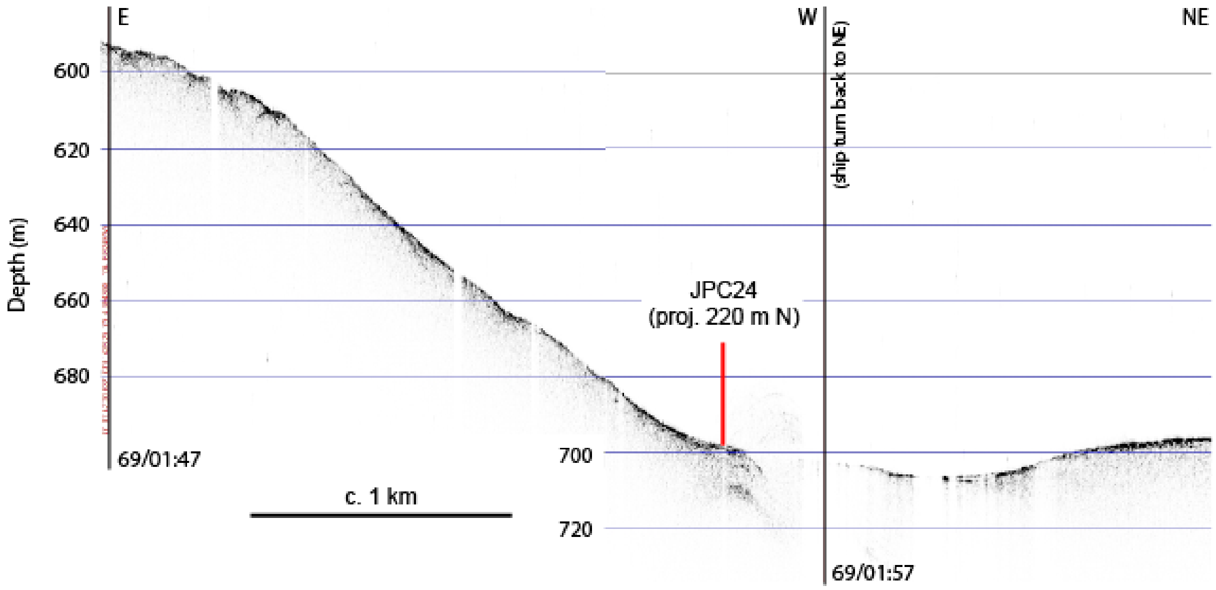
NBP19-02 KC13 & MC14 coring site (74° 54.681' S, 106° 57.201' W)



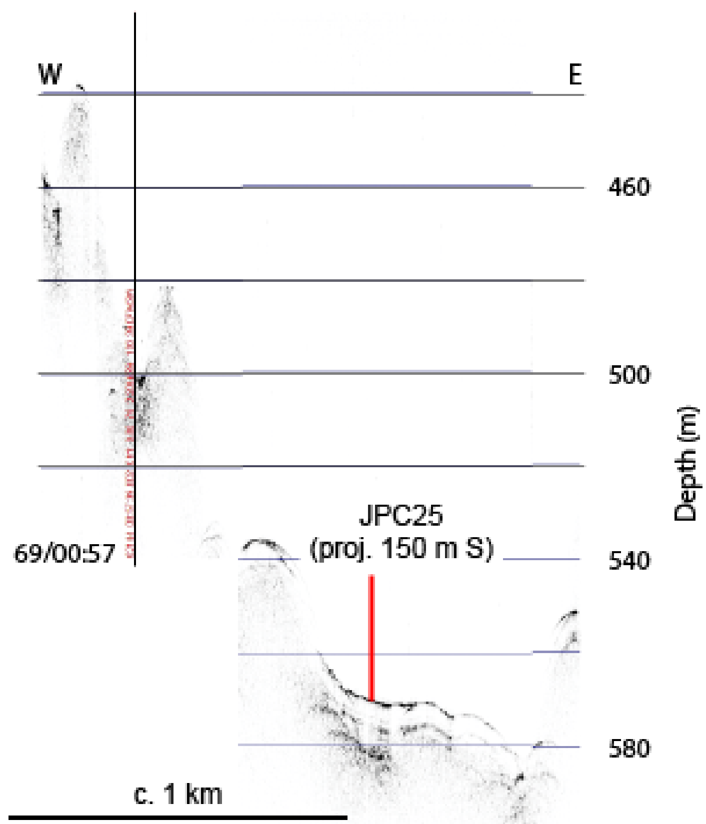

NBP19-02 KC15, MC16, JPC17 & KC19 coring sites
KC19: 74° 51.779' S, 106° 20.479' W; KC15: 74° 52.284' S, 106° 19.981' W;
JPC17: 74° 53.211' S, 106° 18.989' W
Depth (m)
400
450
500
550
600
650
700
750
JPC17
KC15, MC16
KC19
c. 1 km
62/23:38
62/23:38

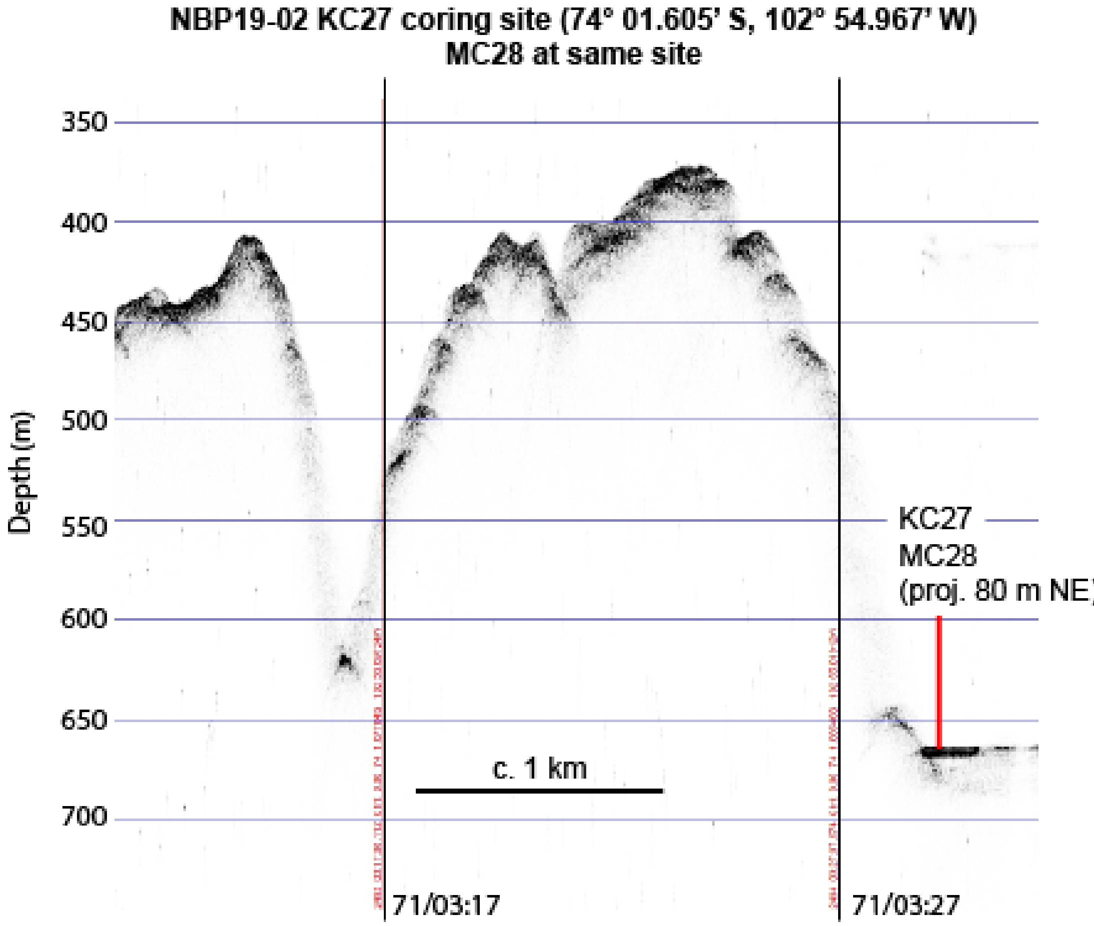

NBP19-02 JPC20 coring site (74° 59.782' S, 106° 17.281' W)
MC22 at same site
Depth (m)
900
950
1000
1050
1100
1150
1200
1250
1300
JPC20
MC22
(proj. 500 m S)
c. 2 km
57/09:19
57/09:29
57/09:39
57/09:59

NBP19-02 JPC24 coring site (75° 04.249' S, 104° 13.706' W)
KC23 at same site



NBP19-02 JPC25 coring site (75° 02.309' S, 103° 40.578' W)
MC26 at approx. same location




NBP19-02 KC27 coring site (74° 01.605' S, 102° 54.967' W)
MC28 at same site
Depth (m)
350
400
450
500
550
600
650
700
KC27
MC28
(proj. 80 m NE)
c. 1 km
71/03:17
71/03:27

Appendix 4. CTD station table

Yixi Zheng

CTD number	Date	Latitude		Longitude		Max depth m	Comments
		Degrees south	Minutes	Degrees west	Minutes		
1	08-FEB-2019	70	27.0969	101	58.1387	3350	Deep cast
2	09-FEB-2019	72	20.6053	103	45.3722	665	
3	10-FEB-2019	73	12.7139	104	19.6953	350	
4	14-FEB-2019	73	33.2400	103	28.0900	507	
5	14-FEB-2019	73	41.9948	103	40.1400	370	
6	14-FEB-2019	73	46.4140	105	36.6389	690	Calibration for mooring
7	14-FEB-2019	73	48.6113	106	32.7686	895	
8	21-FEB-2019	67	34.2010	68	13.3580	514	Cast for Rothera
9	25-FEB-2019	74	12.0177	105	33.9793	1614	Casts in Pine Island Trough
10	26-FEB-2019	74	22.9380	105	4.9210	680	
11	26-FEB-2019	74	32.1400	105	23.6330	952	
12	26-FEB-2019	74	41.2370	105	50.4340	210	
13	27-FEB-2019	74	56.8000	106	52.6420	465	Casts in front of Thwaites Ice Shelf
14	27-FEB-2019	74	56.2289	107	22.9427	1178	
15	28-FEB-2019	75	2.6650	107	7.8860	782	
16	28-FEB-2019	75	0.6300	107	14.8980	900	
17	28-FEB-2019	74	58.4750	107	17.7060	1065	
18	29-FEB-2019	75	4.1418	107	0.239	748	
19	01-MAR-2019	75	4.5927	107	1.8956	653	
20	01-MAR-2019	75	5.5480	107	10.3190	760	
21	01-MAR-2019	75	4.0310	107	11.5030	730	
22	01-MAR-2019	75	3.4550	107	11.3030	760	
23	01-MAR-2019	75	4.5740	107	11.1500	730	
24	01-MAR-2019	75	4.9580	107	14.0300	706	

25	01-MAR-2019	75	5.6460	107	9.1610	767	
26	02-MAR-2019	75	2.6360	107	44.0570	1089	
27	02-MAR-2019	74	59.8390	107	30.4520	1163	
28	02-MAR-2019	74	47.6940	107	27.4310	891	
29	02-MAR-2019	74	49.8051	107	19.3129	994	
30	02-MAR-2019	74	52.2102	107	12.3138	1201	
31	02-MAR-2019	74	53.8953	107	1.2213	625	
32	02-MAR-2019	74	54.9911	106	54.0189	432	
33	03-MAR-2019	75	1.0450	107	52.0020	823	
34	03-MAR-2019	75	1.4470	107	44.2250	1124	
35	03-MAR-2019	75	4.0000	107	40.0340	804	
36	03-MAR-2019	75	2.2000	107	41.2800	1118	
37	03-MAR-2019	74	54.6820	106	57.2240	471	
38	04-MAR-2019	74	59.9000	106	17.4940	1032	
39	04-MAR-2019	74	57.9700	106	18.9310	846	
40	04-MAR-2019	74	56.1010	106	39.3920	413	
41	04-MAR-2019	74	55.9910	106	23.0760	802	
42	04-MAR-2019	74	55.7880	106	14.8720	653	
43	04-MAR-2019	74	55.4820	106	6.9770	425	
44	05-MAR-2019	74	53.6240	106	23.1960	608	
45	05-MAR-2019	74	53.8090	106	24.5200	717	
46	05-MAR-2019	74	54.1420	106	25.9250	782	
47	05-MAR-2019	74	54.3890	106	27.0500	680	
48	06-MAR-2019	74	36.2434	106	37.4217	1134	Calibration for Hugin
49	07-MAR-2019	74	24.8108	106	1.4177	1314	
50	07-MAR-2019	74	37.9680	104	36.0350	1333	Casts in the transit to Pine Island
51	07-MAR-2019	74	47.9755	104	3.0093	1055	
52	07-MAR-2019	74	50.0000	102	50.2030	879	
53	07-MAR-2019	74	51.9869	102	4.5232	941	
54	07-MAR-2019	75	2.8610	102	10.7162	838	Cast in the Pine Island Bay
55	08-MAR-2019	75	8.2560	101	43.0630	920	Casts in front of Pine Island Ice Shelf

56	08-MAR-2019	74	9.4040	101	36.1970	945	
57	08-MAR-2019	75	9.0540	101	28.1450	930	
58	08-MAR-2019	75	7.0345	101	25.5867	1064	
59	08-MAR-2019	75	5.0110	101	20.8550	1070	
60	08-MAR-2019	75	3.7940	101	14.0810	1002	
61	08-MAR-2019	75	2.6257	101	7.8973	987	
62	08-MAR-2019	75	1.3060	101	2.4780	970	
63	08-MAR-2019	75	0.2197	100	56.2148	912	
64	08-MAR-2019	74	59.1847	100	49.8898	857	
65	08-MAR-2019	74	58.1602	100	43.1502	754	
66	08-MAR-2019	74	56.7673	100	37.0532	681	
67	08-MAR-2019	74	54.8561	100	32.8619	510	
68	08-MAR-2019	74	53.0878	100	36.3016	344	
69	09-MAR-2019	75	3.4222	102	10.4604	840	Calibration for mooring
70	09-MAR-2019	74	54.5410	102	42.8840	788	Casts for coastal current
71	09-MAR-2019	75	0.0220	102	44.2502	876	
72	09-MAR-2019	75	2.4849	102	44.0048	729	
73	09-MAR-2019	75	4.5035	102	43.9856	245	
74	09-MAR-2019	75	5.4877	102	43.9989	299	
75	09-MAR-2019	75	6.4934	102	44.0080	232	
76	10-MAR-2019	75	4.2293	104	13.6821	677	Casts near the sea ice edge
77	10-MAR-2019	74	58.5100	104	9.5270	36	
78	10-MAR-2019	74	49.3094	104	30.7919	926	
79	10-MAR-2019	74	43.3713	104	39.4638	910	
80	10-MAR-2019	74	40.4420	104	54.8767	1253	
81	11-MAR-2019	74	37.7234	104	53.1459	1180	
82	11-MAR-2019	74	19.9980	103	9.9130	265	Casts in the south of Edwards Islands
83	11-MAR-2019	74	18.1850	103	16.6020	551	
84	11-MAR-2019	74	15.0370	103	31.9630	828	
85	11-MAR-2019	74	12.9130	103	41.7880	337	
86	11-MAR-2019	74	6.2770	103	5.5980	750	

87	11-MAR-2019	74	0.1910	103	5.5980	738	
88	11-MAR-2019	73	42.9996	103	50.7793	864	Casts in the south of Canisteo Peninsula
89	11-MAR-2019	73	43.9910	103	28.5700	590	
90	12-MAR-2019	74	1.5520	102	55.0570	642	Casts near the Ferrero Bay
91	12-MAR-2019	74	0.5180	102	37.3750	692	Casts near the Cranston Bay
92	12-MAR-2019	74	0.9880	102	39.8560	533	
93	12-MAR-2019	74	0.6110	102	46.8500	789	
94	12-MAR-2019	73	59.9920	102	52.3490	685	
95	12-MAR-2019	73	57.5574	103	3.9560	804	Casts in the deep basin near the Edwards Islands
96	12-MAR-2019	73	42.2552	104	13.4592	610	
97	14-MAR-2019	71	9.6671	107	7.8928	502	Casts for crossing the shelf slope in the Amundsen Sea
98	14-MAR-2019	71	4.8601	106	59.4452	615	
99	14-MAR-2019	71	4.1583	107	0.9055	812	
100	15-MAR-2019	71	3.5360	107	0.8680	968	
101	15-MAR-2019	71	2.3044	107	1.5353	1254	
102	15-MAR-2019	71	1.5092	107	0.2760	1424	
103	15-MAR-2019	71	0.2687	106	58.7242	1696	
104	15-MAR-2019	70	58.4024	106	59.4608	2023	
105	16-MAR-2019	70	27.1408	101	58.0682	3556	Repeat of CTD #1
106	18-MAR-2019	70	1.8791	84	28.3017	425	Casts for crossing the shelf slope in the Bellingshausen Sea
107	18-MAR-2019	69	58.9660	84	30.4900	577	
108	18-MAR-2019	69	56.6990	84	26.9000	808	
109	18-MAR-2019	69	55.3520	84	28.1390	1012	
110	18-MAR-2019	69	53.6810	84	27.7441	1212	
111	18-MAR-2019	69	51.8150	84	27.2500	1402	
112	18-MAR-2019	69	48.2158	84	26.7416	1696	
113	19-MAR-2019	69	40.9610	84	23.5640	2116	

Appendix 5. Water sampling tables and protocols

Yixi Zheng

Appendix 5.1 CTD water sampling

CTD number	Depth (m)	Niskin bottle	Salinometry bottle	Comments
1	3294	1	C02	
1	2000	3	C05	
1	1000	5	C08	
1	600	7	C11	
1	2	9	C14	
2	660	1	C22	
2	550	2	C21	
2	550	3	C20	
2	10	4	C19	
2	10	5	C18	
3	344	1	B01	
3	300	2	B02	
3	2	3	B03	
4	Samples not taken			
5	170	3	B04	Sample bottle broken
5	20	5	B05	
5	4	7	B06	
6	680	1	B07	
6	680	1	B08	
6	680	1	B09	
6	10	7	B10	
6	10	7	B11	
6	10	7	B12	
7	908	1	B13	
7	2	6	B18	
8	Samples not taken; cast for Rothera			
9	1614	1	C24	
9	1000	3	C23	
10	680	1	C17	
10	300	3	B14	
10	2	7	B17	
11	800	1	F01	
12	150	2	F02	
12	50	3	F03	
13	461	1	S09	
13	149	4	S21	
14	1178	1	B19	

14	1178	1	B20	
14	1178	1	B22	Reading labelled as B21 in .dat file? [REJECTED]
14	3	24	S15	
14	3	24	S11	
14	3	24	S06	
15	782	1	F04	
15	200	8	F05	
15	10	14	F06	
16	880	1	F07	
16	10	14	F08	
17	1048	7	F09	
17	150	9	F10	
17	15	11	F11	
18	670	1	B12	Bottle not full: reading not taken
18	2	5	B24	
19	644	1	5 06	
19	644	1	5 18	
19	644	1	5 17	
19	300	8	5 23	
19	300	8	5 22	
19	300	8	5 20	
19	35	10	5 19	
19	35	10	5 12	
19	35	10	5 16	
20	740	5	5 13	
20	10	12	5 14	
21	Samples not taken			
22	740	2	5 11	
23	Samples not taken			
24	701	1	5 09	
24	300	4	5 08	
24	2	8	5 07	
25	761	1	5 05	
25	2	13	5 04	
26	1000	2	I01	
26	1000	2	I02	
26	1000	2	I03	
26	560	4	I04	
26	180	6	I05	
27	1000	2	I07	
27	40	4	I08	
28	886	1	5 02	
28	300	3	B23	
28	2	7	5 01	
29	974	1	5 03	
29	299	3	3 16	

29	1	7	3 10	
30		3	3 18	Either 300 or 800 m
30	1	7	3 05	
31	620	1	3 11	
31	20	7	3 06	
32	416	1	3 01	
32	200	4	3 04	Only two readings, averaged first two
32	10	7	3 17	
33	806	2	H01	
33	806	2	H02	Only two readings, averaged first two
33	806	2	H04	Should be wrong bottle, only one reading. [REJECTED]
33	200	5	H05	
34	1000	2	H06	
34	200	3	H07	
34	30	5	H08	
35	750	2	H09	
36	1000	3	H10	Readings missing from .dat file?
36	40	5	H11	Readings missing from .dat file?
37	200	2	H13	
38	800	4	H22	
38	800	6	H17	
39	700	4	H14	
39	700	4	H15	33.661/34.663/34.66, took three times
39	700	4	H16	
39	200	6	H18	
40	200	2	H19	
40	10	4	H20	
41	750	3	H21	
41	550	4	H23	
41	200	5	H24	
42	210	2	I09	
43	Samples not taken			
44	20	2	I10	
45	200	2	I11	
45	200	2	I12	
45	200	2	I13	
46	680	2	I14	
46	370	3	I15	
46	10	4	I16	
47	680	2	H01	
47	680	2	H05	
47	680	2	H06	
47	475	3	H02	
47	475	3	H07	
47	475	3	H08	
47	15	4	H04	

47	15	4	H09	
47	15	4	H10	
48	1100	4	5 01	
48	400	6	5 02	
48	20	10	5 03	
49	1000	2	B01	
49	1000	2	B02	
49	1000	2	B03	
49	280	3	B05	
49	280	3	B06	
49	280	3	B07	
50	1000	2	5 05	
50	1000	2	5 06	
50	1000	2	5 07	
50	40	3	5 08	
50	40	3	5 09	
50	40	3	H11	
51	1041	2	B08	
51	1041	2	B09	
51	1041	2	B10	
51	30	5	B11	
51	30	5	B12	
51	30	5	B13	
52	700	2	A10	
52	10	8	A11	
53	936	1	S01	
53	150	4	S02	
53	2	12	S03	
53	2	12	S04	
53	2	12	S05	
54	835	1	S07	
54	300	4	S08	
54	3	12	S09	
55	Samples not taken			
56	Samples not taken			
57	Samples not taken			
58	Samples not taken			
59	Samples not taken			
60	Samples not taken			
61	Samples not taken			
62	Samples not taken			
63	Samples not taken			
64	Samples not taken			
65	Samples not taken			
66	Samples not taken			
67	Samples not taken			

68	Samples not taken			
69	800	1	S10	
69	10	2	S11	
70	700	2	S12	
70	700	2	S13	
70	700	2	S14	
70	450	4	S15	
70	10	12	S16	
71	Samples not taken			
72	716	1	S18	
72	200	3	S19	
72	3	9	S20	
73	Samples not taken			
74	283	1	S21	Results vary from 34.1645 to 34.1731, analysed twice
74	15	3	S22	
74	3	8	S23	
75				Samples not taken
76	300	4	I01	
76	300	4	I02	
76	300	4	I03	
76	10	11	I05	
77	2	11	I06	
77	2	11	I07	
77	2	11	I08	
78	889	2	I09	
78	70	3	I10	
79	Samples not taken			
80	50	3	I11	Sample bottles emptied too soon
80	1237	2	I12	Sample bottles emptied too soon
81	1165	2	I13	Sample bottles emptied too soon
82				
83	200	1	I11	
84	700	2	I12	
84	10	7	I13	
85	Samples not taken			
86	Samples not taken			
87	Samples not taken			
88	Samples not taken			
89	Samples not taken			
90	500	1	I15	
90	210	2	I16	
90	10	4	I17	
91	600	2	I18	
92	400	1	I19	
92	10	4	I20	

93	700	1	I21	
93	25	4	I22	
94	Samples not taken			
95	600	2	S17	
95	550	1	S18	
95	2	8	S19	
96	Samples not taken			
97	494	1	B07	
97	494	1	B08	
97	494	1	B09	
97	494	2	B10	
97	494	2	B11	
97	494	2	B12	
98	478	2	S01	
98	478	2	S02	
98	478	2	S03	
98	478	3	S04	
98	478	3	S05	
98	478	3	S06	
99	698	1	S07	
99	698	1	S08	
99	698	1	S09	
99	698	2	S10	
99	698	2	S11	
99	698	2	S12	
100	601	2	A13	
100	601	2	A14	
100	601	2	A15	
100	601	1	A16	
100	601	1	A17	
100	601	1	A18	
101	1000	1	A19	
101	1000	1	A20	
101	1000	1	A21	
101	1000	2	A22	
101	1000	2	A23	
101	1000	2	A24	
102	1200	1	A07	
102	1200	1	A08	
102	1200	1	A09	
102	1200	2	A10	
102	1200	2	A11	
102	1200	2	A12	
103	1400	1	B13	
103	1400	1	B14	
103	1400	1	B15	
103	1400	2	A04	

103	1400	2	A05	
103	1400	2	A06	
104	1400	1	S19	
104	1400	1	S20	
104	1400	1	S21	
104	1400	2	S22	
104	1400	2	S23	
104	1400	2	S24	
105	3001	3	I01	
105	3001	3	I02	
105	3001	3	I03	
105	3001	4	I04	
105	3001	4	I05	
105	3001	4	I06	

Appendix 5.2 Chlorophyll and eDNA sampling protocols

Chlorophyll samples

1. Fill a 2-L polyethylene bottle with water sample from CTD Niskins with Tyon's tubing after rinsing the bottle three times;
2. Put the gloves on;
3. Set up the filter station with a 47 mm GF/G filter and a vacuum of less than 100 mm HG;
4. After shake the water bottle and taking 1 L from the bottle into a 1-L cylinder, immediately filter the water sample through filter;
5. After all the filtrate goes through the filter, rinse the edge the filter station with MilliQ water;
6. Fold the filter once and put it in a 10 cm × 10 cm aluminium foil to cover it and write the detailed information on the foil;
7. Place the filters with aluminium foil from the same CTD station into a labelled plastic bag;
8. Store them in the -80ºC freezer.

eDNA samples

1. Fill two 2-L polyethylene bottle (or equivalent) with water sample from CTD Niskins with Tyon's tubing after rinsing the bottle three times;
2. Put the gloves on;
3. Set up the filter station with an eDNA filter and a vacuum of less than 100 mm HG;
4. Wet the filter with MilliQ water
5. After shaking the water bottles and taking 4 L from the bottles into a 4-L cylinder (or two 2-L cylinders), immediately filter the water sample through filter;
6. After all the filtrate goes through the filter, rinse the edge the filter station with MilliQ water;
7. Fill a 2-ml tube with ATL buffer and label this tube;
8. Fold the filter twice or more and carefully place it into the labelled tube;
9. Use MilliQ water as the "blank" sample and repeat step 3-8;
10. Put the tubes of water sample and "blank" sample into a labelled plastic bag and write the detailed information on this bag;
11. Store them in the -80ºC freezer.

Appendix 5.3 Water sampling for eDNA

CTD number	Depth (m)	Niskin bottle	Chlorophyll bottle	Volume filtered (ml)	Blank	Volume filtered (ml)	Comments
9	1614	1	6, 2	3850	blank	4000	
9	200	6	1, 4	3740			
9	25	24	5, 7	2000			
10	Samples not taken						
11	Samples not taken						
12	200	1	5, 6	3190	blank	4000	
13	461	1	5, 8	4000	blank	4000	Filter for sample was dropped on the table
14	1178	1	1, 5	3720	blank	4000	
14	3	15	8	700	blank	4000	
15	781	2	5, 7	4000	blank	4000	
16	880	1	1, 2	4000	blank	4000	
17	1048	5	8, 1	4000	blank	4000	Filter for blank was dropped on the table
18	Samples not taken						
19	644	1	1, 2 and 4	4000	blank	3000	Water for blank barely goes through filter. Reduced vol to 3 l
20	740	6	1, 4	4000	blank	4000	
21	Samples not taken						
22	740	4	7, 10	4000	blank	4000	
23	Samples not taken						
24	701	1	4-liter	4000	blank	3500	Water for blank barely goes through filter. Reduced vol to 3.5 l
25	761	1	4-liter	4000	blank	4000	
25	627	7	4, 10 and 1	4000			Sediment Flow
26	1035	1	3, 4	4000	blank		
27	Samples not taken						
28	974	1	4-liter	4000	blank	4000	
29	blank						

30	blank						
31	blank						
32	blank						
33	806	4	1,7	4000	blank	4000	
34	blank						
35	blank						
36	1118	2	1, 4	4000	blank	4000	Filter for blank was dropped on the table
37	blank						
38	1123	1	4-liter	4000	blank		
39	Samples not taken						
40	Samples not taken						
41	Bottle fell off table and filter fell to the ground, was discarded						
42	Samples not taken						
43	Samples not taken						
44	590	1	1, 2	3600	blank	4000	44, 45, 46, 47 CTDs used same blank
45	681	1	4, 5	3950			
46	774	1	6, 7	3800			
47	680	1	8, 10	4000			
48	1319	1	4-liter	4000	blank	4000	48, 49 CTDs used same blank
49	1308	1	6, 7	2000			48, 49 CTDs used same blank, only 2000 as barely any water
50	1315	1	6, 7	2000	blank	4000	50, 51 CTDs used the same blank, vol. filtered 3400
51	1041	1	2, 8	3400			
52	859	1	4-liter	4000	blank	4000	
53	Samples not taken						
54	835	1	4-liter	4000	blank	4000	
55	Samples not taken						
56	Samples not taken						
57	Samples not taken						
58	Samples not taken						
59	Samples not taken						
60	Samples not taken						

61	Samples not taken						
62	956	1	1, 2	4000	blank	4000	Blank only
63	Samples not taken						
64	875	1	4-liter	4000	blank	4000	
65	Samples not taken						
66	Samples not taken						
67	498	1	4-liter	4000	blank	4000	
68	Samples not taken						
69	Samples not taken						
70	Samples not taken						
71	862	1	4-liter	4000	blank	4000	71, 73, 75 used same blank
72	Samples not taken						
73	240	1	4-liter	4000	blank	4000	71, 73, 75 used same blank
74	Samples not taken						
75	219	1	4-liter	4000	blank	4000	71, 73, 75 used same blank
76	668	1	3, 4	4000	blank	4000	
77		2	4-liter	4000			77, 78, 79, 81 used same blank
78	889	2	4-liter	4000	blank	4000	77, 78, 79, 81 used same blank
79	872	2	4-liter	4000			77, 78, 79, 81 used same blank
80	Samples not taken						
81	1165	2	4-liter	4000	blank	4000	77, 78, 79, 81 used same blank

Appendix 5.4 Water sampling for chlorophyll

CTD number	Depth (m)	Niskin bottle	Chlorophyll bottle	Volume filtered (ml)	Comments
6	680	2	1	1000	
6	100	4	2	1000	
6	23	6	B	1000	
6	10	8	2	1000	
7	2	6	5	1000	
7	23	4	6	1000	
7	908	1	4	1000	
8	Samples not taken				
9	200	6	10	1000	
9	25	24	8	1000	
10	680	1	1	1000	
10	55	5	6	1000	
10	2	7	4	1000	
11	150	2	2	1000	
11	25	3	7	1000	
11	2	8	10	1000	
12	25	4	1	1000	
12	2	9	5	1000	
13	75	6	6	1000	
13	25	12	4	1000	
13	2	18	10	1000	
14	70	5	4	1000	
14	30	9	6	1000	
14	3	14	10	1000	
15	200	7	1	1000	
15	10	13	2	1000	
16	120	7	4	1000	
16	10	13	6	1000	
17	1048	6	4	1000	
17	150	8	7	1000	
17	15	10	6	1000	
18	Samples not taken				
19	35	10	5	1000	
19	20	12	6	1000	
19	2	18	7	1000	
20	10	11	2	1000	
21	Samples not taken				
22	740	3	5	1000	
22	20	9	8	1000	

23	Samples not taken				
24	40	4	2	1000	
24	2	8	5	1000	
25	2	13	6	1000	
26	180	6	10	1000	
26	30	7	7	1000	
27	200	3	6	1000	
27	40	5	5	1000	
27	2	6	7	1000	
28	30	5	2	1000	
28	2	7	5	1000	
29	30	5	2	1000	
29	2	7	5	1000	
30	30	5	5	1000	
30	1	7	7	1000	
31	20	7	7	1000	
32	10	7	7	1000	
33	806	3	2	1000	
33	200	6	8	1000	
33	20	7	4	1000	
34	200	4	4	1000	
34	30	6	2	1000	
35	200	3	5	1000	
35	25	4	7	1000	
36	200	4	8	1000	
36	40	6	2	1000	
37	Samples not taken				
38	10	8	8	1000	
39	20	8	4	1000	
39	3	13	3	1000	
40	50	3	1	1000	
40	10	5	2	1000	
41	50	6	4	1000	
41	25	7	8	1000	
42	50	3	5	1000	
42	10	4	8	1000	
43	25	2	5	1000	
44	20	3	A	1000	
45	20	3	B	1000	
46	10	5	C	1000	
47	15	5	A	1000	
48	45	8	8	1000	
48	2	12	2	1000	
49	100	4	10	1000	
49	20	5	2	1000	

50	40	4	4	1000	
51	180	3	1	1000	
51	30	4	5	1000	
52	40	7	4	1000	
53	35	6	6	1000	
53	2	12	2	1000	
54	835	1	1	1000	
54	15	6	6	1000	
54	3	12	2	1000	
55	Samples not taken				
56	Samples not taken				
57	Samples not taken				
58	Samples not taken				
59	Samples not taken				
60	Samples not taken				
61	Samples not taken				
62	Samples not taken				
63	Samples not taken				
64	Samples not taken				
65	Samples not taken				
66	Samples not taken				
67	Samples not taken				
68	Samples not taken				
69	Samples not taken				
70	40	6	6	1000	
70	2	14	4	1000	
71	Samples not taken				
72	15	4	4	1000	
72	3	9	9	1000	
73	Samples not taken				
74	15	3	3	1000	
74	3	8	8	1000	
75	Samples not taken				
76	25	6	1	1000	
76	3	13	2	1000	
77	2	12	1	1000	
78	25	4	4	1000	
79	15	4	4	1000	
80	15	4	4	1000	The filter was left uncovered for 2 hours
81	10	3	3	1000	
82	Samples not taken				
83	80	2	2	1000	
83	20	3	3	1000	
84	Samples not taken				
85	Samples not taken				

86	15	3	1	1000	
87	Samples not taken				
88	50	4	4	1000	
88	25	9	9	1000	
89	10	6	6	1000	
90	100	3	4	1000	
90	10	5	9	1000	
91	Samples not taken				
92	80	2	1	1000	
92	35	3	4	1000	
93	70	2	6	1000	
93	25	3	7	1000	
94	Samples not taken				
95	25	3	3	1000	
96	25	2	2	1000	
96	2	3	1-liter	1000	

Appendix 5.5 Thermosalinograph water samples

TSG sample number	Salinity (PSU) From TSG on screens	Salinom-etry bottle	Latitude		Longitude		Date	Time (UTC)
			Degrees south	Minutes	Degrees west	Minutes		
1	33.222	S10	75	5.4170	106	9.1370	27-FEB-2019	13:49
2	33.227	5 15	75	4.591	107	2.061	01-MAR-2019	2:32
3	33.185	43595	75	4.209	107	0.095	01-MAR-2019	20:39
4	33.267	I06	74	59.6800	107	30.0842	02-MAR-2019	9:15
5	33.211	3 03	74	54.7200	106	32.6090	02-MAR-2019	23:47
6	33.240	3 07	75	1.0500	107	52.1350	03-MAR-2019	4:44
7	33.290	3 13	75	1.4370	107	44.1110	03-MAR-2019	5:57
8	33.280	3 14	75	3.9800	107	40.0370	03-MAR-2019	8:16
9	33.308	3 15	75	2.1800	107	41.3770	03-MAR-2019	10:28
10	33.269	H12	74	54.7520	106	57.2370	03-MAR-2019	14:42
11	33.570	3 02	74	57.9430	106	18.7860	04-MAR-2019	2:36
12	33.681	A01	74	57.9430	106	18.7860	04-MAR-2019	3:18
13	33.272	A02	74	56.1010	106	29.4656	04-MAR-2019	4:27
14	33.261	A03	74	55.9900	106	23.0960	04-MAR-2019	6:22
15	33.566	A04	74	55.7910	106	14.9820	04-MAR-2019	7:17
16	33.866	A05	74	55.4820	106	6.9390	04-MAR-2019	8:17
17	33.286	A06	74	53.8180	106	24.5290	05-MAR-2019	11:37
18	33.297	A07	74	54.1200	106	25.7530	05-MAR-2019	13:14
19	33.313	3 04	74	54.1030	106	25.5280	05-MAR-2019	1:43
20	33.458	A08	74	59.7820	106	17.2220	06-MAR-2019	11:53
21	33.581	5 04	74	31.2140	106	21.0390	07-MAR-2019	1:38
22	33.393	A09	74	24.8590	106	1.3740	07-MAR-2019	3:30
23	33.845	3 12	74	37.9710	104	36.0310	07-MAR-2019	7:37
24	33.486	S06	74	51.6490	102	7.3620	07-MAR-2019	17:13
25	33.672	S17	74	59.5070	102	44.0360	09-MAR-2019	17:35
26	33.604	5 12	74	32.2810	104	20.3500	11-MAR-2019	3:02

Appendix 6. Glider deployment and recovery table

B.Y. Queste

ACTIVITY	NAME	DATE	LAT	LON
Deploy	SG620 (UEA)	10 Feb 19	73° 12.71’ S	104° 19.70’ W
Recover	SG620 (UEA)	13 Feb 19	73° 33.34’ S	103° 26.48’ W
Recover	SG621 (Caltech)	23 Feb 19	70° 01.65’ S	93° 01.69’ W
Deploy	SG620 (UEA)	26 Feb 19	74° 56.46’ S	107° 22.69’ W
Deploy	SG621 (Caltech)	01 Mar 19	75° 02.19’ S	107° 10.09’ W
Recover	SG621 (Caltech)	02 Mar 19	75° 02.19’ S	107° 10.09’ W
Recover	SG620 (UEA)	03 Mar 19	74° 58.06’ S	107° 31.03’ W
Deploy	SG620 (UEA)	04 Mar 19	74° 55.00’ S	109° 19.59’ W
Recover	SG620 (UEA)	05 Mar 19	74° 57.08’ S	106° 20.38’ W

Appendix 7. Hugin AUV and cNODE deployment and recovery table

Aleksandra Mazur

Mission	cNODE position	AUV deployment time	AUV deployment position	AUV recovery time	AUV recovery position
NBP1902_001 (1 cNODE)	53˚1.977'S 73˚40.708'W	01-FEB-2019 16:22	52˚57.649'S 73˚39.003'W	01-FEB-2019 20:49	53˚3.778'S 73˚46.41'W
NBP1902_002 (mission aborted)		10-FEB-2019 5:49	73˚12.604'S 104˚20.185'W	10-FEB-2019 06:24	73˚12.604'S 104˚20.185'W
NBP1902_003 (mission aborted)		10-FEB-2019 8:58	73˚12.71'S 104˚19.69'W	10-FEB-2019 12:45	73˚12.5776'S 104˚10.646'W
NBP1902_004 (buoyancy test)		11-FEB-2019 05:34	73˚57.706'S 103˚13.987'W	11-FEB-2019 07:14	Approx. the same position where it was deployed
NBP1902_005 (DVL test)		13-FEB-2019 03:05	73˚39.20'S 103˚17.07'W	13-FEB-2019 05:41	73˚39.29'S 103˚18.729'W
NBP1902_006 (mission name changed to NBP1902_007		13-FEB-2019 11:39	73˚34.71'S 103˚11.87'W	14-FEB-2019 9:55	73˚33.7'S 103˚15.05'W
NBP1902_008		20-FEB-2019 16:20	68˚8.177'S 67˚34.596'W	20-FEB-2019 18:24	Approx. the same position where it was deployed
NBP1902_009 (2 cNODEs)	75˚05.78'S 107˚10.65'W 75˚05.78'S 107˚10.65'W	28-FEB-2019 22:07	75˚04.21'S 106˚58.89'W	01-MAR-2019 15:33	75˚05.049'S 107˚10.925'W
NBP1902_010 (4 cNODEs)	74˚59.923'S 106˚16.905'W 74˚57.616'S 106˚12.768'W 74˚57.621'S 106˚12.833'W 74˚53.448'S 106˚23.021'W	05-MAR-2019 09:34	74˚57.236'S 106˚15.733'W	06-MAR-2019 03:17	74˚54.054'S 106˚25.619'W

Appendix 8. XBT cast table

James Kirkham

XBT number	Station	Latitude °S	Longitude °W	Launch Date	Launch time	File name	Location
XBT01	002	59° 59.5498’	84° 52.1260’	05-FEB-2019	01:32	TD_00003	On transit to Amundsen Sea
XBT02	003	65° 18.1494’	92° 21.6074’	06-FEB-2019	15:30	TD_00034	On transit to Amundsen Sea
XBT03	004	69° 30.5220’	99° 47.8008’	07-FEB-2019	23:42	TD_00035	On transit to Amundsen Sea
XBT04	024	69° 11.5923’	92° 31.5020’	17-FEB-2019	17:42	TD_00036	On transit to Rothera
XBT05	025	68° 51.1836’	86° 07.1436’	18-FEB-2019	04:36	TD_00037	On transit to Rothera
XBT06	026	67° 57.3892’	70° 36.2305’	19-FEB-2019	08:01	TD_00038	On transit to Rothera
XBT07	031	72° 40.8799’	108° 17.2705’	25-FEB-2019	11:54	TD_00041	On transit back to Thwaites Glacier area
XBT08	037	74° 51.6475’	107° 12.3281’	26-FEB-2019	17:55	TD_00042	Thwaites western deep trough
XBT09	173	64° 33.8628’	76° 59.8965’	20-MAR-2019	22:40	TD_00044	On transit back

All XBT probes deployed were Sippican ‘Deep Blue’ type.

Appendix 9. Table of seal tagging locations

Guilherme A. Bortolotto de Oliveira

Table A9.1. Locations of tag deployments on seals. (Date format is “day-month-year” [dd/mm/yyyy]; latitude and longitude format is “degree-decimal minute” [DD° MM,MMM]; SES = southern elephant seal; WES = Weddell seal; F = female; M = male; U = unidentified).

Date	Latitude	Longitude	Species	Sex	Tag	Deployment ID
10/02/2019	-73° 52.396	-102° 59.304	SES	F	14863	ct147-EF863-19
12/02/2019	-73° 39.058	-103° 12.857	WES	U	14867	ct147-WU867-19
12/02/2019	-73° 39.058	-103° 12.857	WES	M	14870	ct147-WM870-19
13/02/2019	-73° 36.603	-103° 02.290	WES	M	14872	ct147-WM872-19
04/03/2019	-74° 42.051	-105° 49.360	WES	M	14864	ct147-WM864-19
04/03/2019	-74° 39.831	-105° 52.943	WES	U	14894	ct147-WU894-19
11/03/2019	-73° 52.570	-102° 57.350	WES	M	14897	ct147-WM897-19
11/03/2019	-73° 52.578	-102° 57.334	WES	F	14871	ct147-WF871-19
11/03/2019	-73° 52.594	-102° 59.936	WES	F	14891	ct147-WF891-19
11/03/2019	-73° 52.179	-102° 58.415	WES	U	14869	ct147-WU869-19
12/03/2019	-73° 52.060	-102° 58.318	WES	F	14868	ct147-WF868-19
12/03/2019	-73° 52.060	-102° 58.318	WES	M	14898	ct147-WM898-19

Appendix 10. Geological History Contraints (GHC) Project site location table

Scott Braddock, Meghan Spoth

Table A10.2. Island sites investigated and sampled for GHC project. (Date format is “month-day-year” [mm/dd/yyyy]; latitude and longitude format is “degree-decimal minute” [DD° MM,MMM].

Island name	Date	Latitude		Longitude		Number of Samples
Edwards 1	02/10/2019	-73°	52.667	-102°	59.693	49
Schaefer 1	02/12/2019	-73°	38.464	-103°	13.342	73
Lindsey 1	02/13/2019	-73°	36.373	-103°	2.558	36
Edwards 2	03/12/2019	-73°	52.478	-102°	59.070	38
Edwards 3	03/12/2019	-73°	51.914	-103°	0.825	49

Appendix 11. Oceanographic mooring locations

Mark Barham

Table A11.1. Locations of mooring sites visited. Date format is "day-month-year" [dd/mm/yyyy].

Mooring	**Deployment date and time (UTC)**	**Recovery date and time (UTC)**	**Latitude (DD MM.m)**	**Longitude (DDD MM.m)**	**Latitude (DD.d)**	**Longitude (DD.d)**	**Depth (m)**
Mid-shelf	15/02/2019 09:30	14/02/2019 22:10	73°S 48.729'	106°W 31.982'	-73.8121	-106.5330	973
target:		-	73°S 48.759'	106°W 32.120'	-73.8127	-106.5353	913
PIG_S	09/03/2019 09:58	Mooring not found	75°S 03.278'	102°W 09.526'	-75.0546	-102.1588	841
target:		-	75°S 03.317'	102°W 09.262'	-75.0553	-102.1544	810
PIG_N	No mooring deployed in 2019	07/03/2019 18:35					
target:		-	74°S 51.790'	102°W 06.250'	-74.8632	-102.1042	954

Table A11.2. Locations of mooring sites not visited due to persistent ice cover. Date format is "day-month-year" [dd/mm/yyyy].

Mooring	**Deployment date and time (UTC)**	**Recovery date and time (UTC)**	**Latitude (DD MM.m)**	**Longitude (DDD MM.m)**	**Latitude (DD.d)**	**Longitude (DD.d)**	**Depth (m)**
Trough_E	04/02/2016 13:01		71°S 20.175'	102°W 30.234'	-71.3362	-102.5039	638
target:		-	71°S 20.095'	102°W 30.738'	-71.3349	-102.5123	638‡
Trough_W	07/02/2016 21:09		71°S 33.729'	113°W 02.768'	-71.5622	-113.0461	605
target:		-	71°S 33.732'	113°W 02.759'	-71.5622	-113.0460	600

Appendix 12. Gravity base ties

G. Aukon, B. Bjork and R. Larter

The following pages contain details of the gravity base ties conducted at Muelle Prat, Punta Arenas on January 28th and March 27th 2019. The ties were made to a base station located at the foot of the steps outside the harbour administration building, on the side facing the pier (IGSN station number 51230N, value of gravity 981320.82 mGal).

Table A12.1. Gravity tie conducted at Punta Arenas on January 28th 2019.

Gravity Tie Spreadsheet

The fields outlined in BOLD MUST BE FILLED IN for this spreadsheet to operate properly. The automatically calculated values show up in the shaded fields.

Date:	1/28/2019	Reference Code Numbers:	
Location:	**Punta Arenas, Chile**	Station no.	9337-50
Station:	Harbour Admin. Bldg.	ISGN no.	51230N
Latitude:	53 09 S		
Longitude:	070 55 W		
Elevation:			
Gravity:	981320.82		

	Value	Time (GMT)
Ship's meter before gravity tie (Filt Counts)	25190.32	15:35
Ship's meter after gravity tie (Filt Counts)	25190.35	0:00
Average	25190.34	
Ship Gravimeter's Calibration Constant	4.99407055	
Corrected ship's meter (QC Grav (mgal))	125802.31	

	Value	Time (GMT)
Ship's meter before gravity tie (serial, RVDAS)	981273.5	15:31
Ship's meter after gravity tie (serial, RVDAS)	981293.4	0:00
Average (for comparison check only)	981283.5	

Portable Gravimeter Interval Factor	1.01007	From Table 1 of Model G #807 Meter

Station	Value	Time (GMT)	Temp	Date	OBS mgal, averaged
Pier measurement 1	4911.10	16:00	53.6	January 28, 2019	
Pier measurement 2	4911.03	16:05	53.6	January 28, 2019	4960.49
Pier measurement 3	4910.99	16:06	53.6	January 28, 2019	
Average	4911.04				
Station measurement 1	4911.84	16:23	53.6	January 28, 2019	
Station measurement 2	4911.83	16:25	53.6	January 28, 2019	4961.30
Station measurement 3	4911.84	16:28	53.6	January 28, 2019	
Average	4911.84				
Pier measurement 4	4911.20	16:40	53.6	January 28, 2019	
Pier measurement 5	4911.22	16:43	53.6	January 28, 2019	4960.67
Pier measurement 6	4911.22	16:44	53.6	January 28, 2019	
Average	4911.21				

Date of last tie	10/13/2018
Gravity Bias from last tie	855517.59
Drift since last tie	0.53
Drift RATE since last tie	0.15

OBS Differences

Station to Pier (1, 2, & 3 averaged)	-0.80
Station to Pier (4, 5, & 6 averaged)	-0.63
Averaged Differences	-0.72
Gravity at pier	981320.10
Elevation of pier above gravimeter, meters	1.1
Earth differential gravity, mgal/meter	0.3
Gravity at ship's gravimeter	981320.43
Gravity Bias **(for reference only)**	855518.12
Gravity Bias from GUI **(USE IN RVDAS)**	855519.67

Comments

Tie done by Barry Bjork & Sheldon Blackman, Some vibration on the pier. ***Note:*** **These values are for reference only. Use final BIAS value from gravity tie GIU in laptop software to enter into RVDAS.**

Note about Elevation of Pier: *If pier is below the ship's gravimeter, this value is negative. If above, positive.*

BGM3 land tie report

Barry Bjork, Sheldon Blackman, vessel: R/V Palmer

Release Date: 2019/01/28 17:18:32 UTC

Sensor: S210
Land meter: G-807
Land meter temperature: 53.6
Software version: 1.2
Reference station: B
Reference station name: Harbour Admin Bldg
Reference station number: 9337-50 (3)
Reference mGal: 981320.82
Reference latitude: -53.15
Reference longitude: -70.9166667
New station: A
New station mGal: 981320.11472005
New station latitude: -53.17
New station longitude: -70.9
Notes:

Table A12.2. Land meter measurements made on January 28th 2019. Station A was located on the pier alongside the ship. Station B was the IGSN base station outside the harbour administration building.

Station	Time	Reading	mGal
A	2019/01/28 16:00:00	4911.1	4950.111777
A	2019/01/28 16:03:00	4911.03	4950.0410721
A	2019/01/28 16:06:00	4910.99	4950.0006693
B	2019/01/28 16:23:00	4911.84	4950.8592288
B	2019/01/28 16:25:00	4911.83	4950.8491281
B	2019/01/28 16:28:00	4911.84	4950.8592288
A	2019/01/28 16:40:00	4911.2	4950.212784
A	2019/01/28 16:43:00	4911.22	4950.2329854
A	2019/01/28 16:44:00	4911.22	4950.2329854

Table A12.3. Drift corrections applied to the land meter measurements in Table A12.2.

Station	Avg time	Avg mGal	drift (mGal/min)	Drift corr mGal
A	2019/01/28 16:03:00	4950.0511728	7.4185932203749e-05	4950.0511728
B	2019/01/28 16:25:20	4950.8558619	7.4185932203749e-05	4950.7564527508
A	2019/01/28 16:42:20	4950.2262516	7.4185932203749e-05	4950.0511728

BGM3 ship-to-shore gravity tie report

Barry Bjork, Sheldon Blackman, vessel: R/V Palmer Release

Date: 2019/01/28 18:24:11 UTC

Table A12.4. Summary of information from gravity tie conducted on January 28th 2019.

Sensor: S210 Software
version: 1.2
Port/Pier/Berth: Pratt Pier

Gravity station number	9337-50 (3)
Station name	Harbour Admin Bldg
mGal at pier	981320.82
Tie start time UTC	2019/01/28 17:23:53.388
Samples used	3600
Land tie used	Yes
Water height to pier 1	12 ft 0 in
Water height to pier 2	11 ft 6 in
Water height to pier 3	11 ft 0 in
Average of filtered counts	25190.318653028
Filter length	361
Scale factor	4.994070552
NEW BIAS	**855519.67**

Chief Scientist's note: The 'mGal at pier' value in the table above is the value of gravity of the base station. In my opinion the 'New Station' value calculated in the BGM3 Land Ties Report (981320.115 mGal) for gravity on the pier alongside the ship should have been used here instead. After correction for elevation difference of 1.1 m, this would mean gravity at the ship's meter was 981320.445 mGal. Given the average of filtered counts value above this would mean a NEW BIAS value 855518.216 should have been used to yield accurate values of gravity at the gravity meter. Alternatively, if gravity at water level is desired this requires an additional correction for elevation difference of 2.4 m. This would mean gravity at water level was 981321.225 mGal, which given the average filtered counts value above would mean a NEW BIAS value of 855518.996. However, the NEW BIAS value in the table above was the one used in RVDAS and therefore set all the logged gravity values.

Table A12.5. Gravity tie conducted at Punta Arenas on March 27th 2019.

Gravity Tie Spreadsheet

The fields outlined in BOLD MUST BE FILLED IN for this spreadsheet to operate properly. The automatically calculated values show up in the shaded fields.

Date: 27/03/2019
Location: Punta Arenas, Chile
Station: Harbour Admin. Bldg.
Latitude: 53 09 S
Longitude: 070 55 W
Elevation:
Gravity: 981320.82

Reference Code Numbers:
Station no. 9337-50
ISGN no. 51230N

	Value	Time (GMT)
Ship's meter before gravity tie (Filt Counts)	25189.85	11:41
Ship's meter after gravity tie (Filt Counts)	25189.85	12:42
Average	25189.85	
Ship Gravimeter's Calibration Constant	4.99407055	
Corrected ship's meter (QC Grav (mgal))	125799.89	

	Value	Time (GMT)
Ship's meter before gravity tie (serial, RVDAS)	981283.0	11:48
Ship's meter after gravity tie (serial, RVDAS)	981778.0	12:42
Average (for comparison check only)	981530.5	

Portable Gravimeter Interval Factor: 1.01007 From Table 1 of Model G #807 Meter

Station	Value	Time (GMT)	Temp	Date	OBS mgal, averaged
Pier measurement 1	4911.71	11:50	53.5	March 27, 2019	
Pier measurement 2	4911.68	11:54	53.5	March 27, 2019	4961.15
Pier measurement 3	4911.67	11:55	53.5	March 27, 2019	
Average	4911.69				
Station measurement 1	4912.47	12:06	53.5	March 27, 2019	
Station measurement 2	4912.52	12:08	53.5	March 27, 2019	4961.97
Station measurement 3	4912.50	12:11	53.5	March 27, 2019	
Average	4912.50				
Pier measurement 4	4911.66	12:32	53.5	March 27, 2019	
Pier measurement 5	4911.72	12:34	53.5	March 27, 2019	4961.15
Pier measurement 6	4911.70	12:37	53.5	March 27, 2019	
Average	4911.69				

Date of last tie	28/01/2019
Gravity Bias from last tie	855518.12
Drift since last tie	2.30
Drift RATE since last tie	1.20

OBS Differences

Station to Pier (1, 2, & 3 averaged)	-0.82
Station to Pier (4, 5, & 6 averaged)	-0.81
Averaged Differences	-0.81
Gravity at pier	981320.01
Elevation of pier above gravimeter, meters	1.0
Earth differential gravity, mgal/meter	0.3
Gravity at ship's gravimeter	981320.31
Gravity Bias **(for reference only)**	855520.42
Gravity Bias from GUI **(USE IN RVDAS)**	

Comments

Tie done by Barry Bjork & George Aukon, Some vibration on the pier. *Note:* These values are for reference only. Use final BIAS value from gravity tie GIU in laptop software to enter into RVDAS.

Note about Elevation of Pier: *If pier is below the ship's gravimeter, this value is negative. If above, positive.*

BGM3 land tie report

G. Aukon, B.Bjork, vessel: R/V Palmer Release

Date: 2019/03/27 13:00:08 UTC

Sensor: S210
Land meter: G-807
Land meter temperature: 53.5
Software version: 1.2
Reference station: B
Reference station name: Harbour Admin Bldg
Reference station number: 9337-50 (3)
Reference mGal: 981320.82
Reference latitude: -53.15
Reference longitude: -70.9166667
New station: A
New station mGal: 981320.00430167
New station latitude: 0
New station longitude: 0
Notes:

Table A12.6. Land meter measurements made on March 27th 2019. Station A was located on the pier alongside the ship. Station B was the IGSN base station outside the harbour administration building.

Station	Time	Reading	mGal
A	2019/03/27 11:50:00	4911.71	4950.7279197
A	2019/03/27 11:54:00	4911.68	4950.6976176
A	2019/03/27 11:55:00	4911.67	4950.6875169
B	2019/03/27 12:06:00	4912.47	4951.4955729
B	2019/03/27 12:08:00	4912.52	4951.5460764
B	2019/03/27 12:11:00	4912.5	4951.525875
A	2019/03/27 12:32:00	4911.66	4950.6774162
A	2019/03/27 12:34:00	4911.72	4950.7380204
A	2019/03/27 12:39:00	4911.7	4950.717819

Table A12.7. Drift corrections applied to the land meter measurements in Table A12.5.

Station	Avg time	Avg mGal	drift (mGal/min)	Drift corr mGal
A	2019/03/27 11:53:00	4950.7043514	2.6721428571003e-06	4950.7043514
B	2019/03/27 12:08:20	4951.5225081	2.6721428571003e-06	4951.5200497286
A	2019/03/27 12:35:00	4950.7110852	2.6721428571003e-06	4950.7043514

BGM3 ship-to-shore gravity tie report

G.Aukon, B. Bjork, vessel: R/V Palmer

Release Date: 2019/03/27 14:06:29 UTC

Table A12.8. Summary of information from gravity tie conducted on March 27th 2019.

Sensor: S210 Software
version: 1.2
Port/Pier/Berth:

Gravity station number	9337-50 (3)
Station name	Harbour Admin Bldg
mGal at pier	981320.82
Tie start time UTC	2019/03/27 13:04:47.986
Samples used	3600
Land tie used	No
Water height to pier 1	4 ft 4 in
Water height to pier 2	5 ft 0 in
Water height to pier 3	5 ft 4 in
Average of filtered counts	25189.860837306
Filter length	181
Scale factor	4.994070552
NEW BIAS	**855521.34**

Chief Scientist's note: The 'mGal at pier value in the table above is the value of gravity of the base station. In my opinion the 'New Station' value calculated in the BGM3 Land Ties Report (981320.004 mGal) for gravity on the pier alongside the ship should have been used here instead. After correction for elevation difference of 1 m, this would mean gravity at the ship's meter was 981320.304 mGal. Given the average of filtered counts value above this would make the NEW BIAS value 855520.362. The water height to pier measurements in the table above seem inconsistent with the 'Elevation to pier above gravimeter' measurement of 1.0 m in table A12.5. My understanding is that meter drift calculated from the gravity ties has not been applied to the data in RVDAS.

Appendix 13. Typical sonar system parameter settings

Kelly Hogan

EM122 Acquisition Parameters

MBES screen, "EM122 Runtime Menu"

Ping Mode: AUTO (but was sometimes set to MEDIUM or DEEP fixed depth mode to try to remove sector boundaries at intermediate water depths)

Sector Coverage

Max Port Angle:	30 - 68°
Max Starboard Angle:	30 - 68°
Angular Coverage:	Auto
Beam Spacing:	HD Equidistant

Pitch stabilization: On

Yaw stabilization: On in 'Rel. Mean Heading' mode; Heading filter MEDIUM

Min Depth: used to constrain depth when in ice

Max Depth: used to constrain depth when in ice

Dual swath mode: FIXED

Sound Speed at Transducer:

Sound Speed:	1453.9 m/s
From:	Sensor
Sensor Offset:	0.0 m/s
Filter:	60 s

Filter and Gains

Spike Filter Strength:	Medium
Range Gate:	Normal
Phase Ramp:	Normal

Penetration Filter Strength: Off

Aeration: Off

Sector Tracking: On

Slope: On

Interference: Off

Absorption Coefficient

Source: Salinity

Salinity (parts per thousand): 35.6

Normal incidence sector

Angle from nadir (deg.): 6

Mammal protection

TX power level (dB): Max

Soft startup ramp time (min.):0

Water Column

30 log R; 20 dB Offset

Data Cleaning

Set to NONE

Rule set: AUTOMATIC1

Knudsen Sub-Bottom Profiler Acquisition Parameters

Ch1: 3.5 kHz Menu

Tx Pulse:	2 or 4 ms
Tx Power:	1 or 2
Gain Mode:	Manual
Gain Value:	Variable e.g. 20 dB
TVG Mode:	Variable (None, 5 logR, 10 logR typical)
Process Shift:	0
Sensitivity:	Off
Draft:	7.00
Tx Blanking	0.0
Primary Channel	Ticked on
Range:	500 (or 200 when surveying core sites)
Phase	
Mode:	Manual
Overlap:	50%
Phase:	Variable around seabed depth
Shift Threshold:	10%
Depth Limits	
Minimum:	250
Maximum:	6000
Multiple Pings:	Disabled
Miscellaneous	
Working Units:	Meters
Sounds Speed:	1500
Ping Rate:	13000 ms
Tracking Gate:	2

Echogram:	Heave Compensated
Synchronisation Mode:	Internal

Usage Configuration Menu

Waveform:		Chirp
Center Frequency/Bandwidth		
	Frequency	3.5 kHz
	Bandwidth	3.0 kHz
	Stop/start:	2.308
		5.308
Envelope Detect:		Square Law
Filtering Window		
	Main signal	Rectangular
	Analytic	Rectangular
	Lowpass	Rectangular
	Transmit	Rectangular
	SEGY Carrier Type	None

Echogram Chart Setup

Contrast:	0
Display Mode:	Overlayed
Colour Mode:	Greyscale
Embedded Text:	Disabled
Grid Mode:	Coarse
Overlays:	Heave Indicator