RV *Investigator* Voyage Scientific Highlights and Summary

Voyage #:	IN2018_V05		
Voyage title:	How does a standing meander southeast of Tasmania brake the Antarctic Circumpolar Current?		
Mobilisation:	Hobart, Tuesday, 16 October 2018		
Depart:	Hobart, Tuesday, 16 October 2018		
Return:	Hobart, Friday, 16 November 2018		
Demobilisation:	Hobart, Friday, 16 November 2018		
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Piggy-back Project name:	Upper ocean biogeochemistry in the Macquarie Meander of the Antarctic Circumpolar Current		

Principal Investigators:	Dr Pete Strutton		
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Scientific Highlights

The Chief Scientists

Nathan Bindoff and Helen Phillips are Physical Oceanographers based at the University of Tasmania.

Professor Bindoff has been studying signals of change in the ocean from measurements, like oxygen levels, temperature and salinity, from the 1970s to the present. He is one of the coordinating lead authors contributing to the Intergovernmental Panel on Climate Change (IPCC) AR6 reports that are informing world leaders on climate policy.

Dr Phillips' interest is in how small-scale features in the ocean, such as waves and eddies, affect the large currents that are critical pathways for heat and other properties to be spread through the ocean. She is an observational oceanographer, spending time on research vessels, but also using autonomous instruments to collect data remotely and send home over the mobile phone network.

Title

How does a standing meander brake the Antarctic Circumpolar Current?

Purpose

The volume of water carried by the Antarctic Circumpolar Current (ACC) has not increased despite significant strengthening of the Southern Ocean westerlies over the past 20 years. This is a big surprise given what we understand about wind forcing of ocean currents. The oceanographic community has proposed many ideas for why this is so, based on theory and computer models. Yet, there are very few observations to test these ideas. Our voyage delivered an impressive suite of observations that when combined with a super high-resolution model of the region will allow us to study the mechanisms and give insight into reasons for the constant flow of the ACC.

The target region for the voyage was a permanent meander in the Polar Front (a branch of the ACC) south of Tasmania. The meander is likely to exist because of the sharp change in water depth as the ACC passes over the southeast Indian Ridge. The meander flexes and steepens in response to changes in the winds and currents and this leads to the formation of energetic eddies. The eddies are a central element of the transfer of heat toward Antarctica and to slowing or braking the ACC's flow.

Our voyage consisted of 4 main parts

1. Deployment of a tall mooring to record the temperature, salinity and ocean currents from the surface to the sea floor over the course of 2 years.
2. Deployment of a fleet of EM-APEX profiling floats to measure the variations in ocean currents and water properties along the Polar Front
3. Full-depth hydrographic survey of the physics and biogeochemistry of the Polar Front meander, conducting transects across the front. This will include CTD/LADCP profiles, water sample analysis, VMP-2000 microstructure profiles, bathymetry and underway instruments.

4. Triaxus transects across the Polar Front to measure the detailed variations in physical and biogeochemical water-mass properties in the upper 300 m. Coincident meteorological and shipboard ADCP measurements will allow investigation of air-sea interactions.

Contribution to the nation

Our work contributes to understanding the boundaries to the Southern Ocean's adaptability to increasing winds and the limits that this might place on the global overturning circulation, and uptake of heat and carbon dioxide by the ocean.

We are increasing Australia's skill base by training the next generation of marine scientists in state of the art observing and analysis methods. We will enhance the international collaboration and competitiveness of Australian research by partnering with world-leading teams in this field at a time when the Southern Ocean is of intense interest to the international community.

Our project addresses a critical gap in knowledge of the role of the Southern Ocean in the global climate system: How does interaction of the ACC with topography slow the current and enable the cross-stream heat fluxes that maintain a global overturning circulation? Our improved understanding will lead to enhanced performance of coupled earth system models through improved representation of the dynamics of Southern Ocean processes, providing more robust analysis of climate change to guide domestic and international responses.

Through the involvement of 15 students in our project, we are contributing to the development of the next generation of marine and climate scientists to support the national research effort and to promote careers in STEM. The students participated in analysis of the observations we collected and in the communication activities on the voyage. Many of the preliminary results were prepared by the students and ECRs.

Our data will be made publicly available and will support high quality research by experienced investigators and research students to address fundamental questions on the role of the Southern Ocean in the climate system and links to Australian and regional climate variability.

As a result of this voyage

1. We have a better understanding of:
    - The vertical and horizontal structure of the Polar Front (speed, direction and water properties) and how these properties are modified as the water passes through the meander. Our survey is the most comprehensive assessment of the physical and biogeochemical structure of an ACC front.
2. We have found:
    - Water entering a Polar Front meander is modified substantially along its passage through the meander.
    - Strong currents extend all the way to the sea floor, with strongest flows most often found where the sea floor is smooth.
    - Large amounts of heat are released to the atmosphere on the northern side of the front.

  - Meander crests and troughs are the spawning ground for intense eddies that remain within the meander because they are appear to be trapped by the shape of the sea floor.
3. We have mapped:
   - The velocity, density and biogeochemical structure of a full meander in the ACC in a region where interaction of the current and bathymetry is likely to slow the ACC.
4. We have commenced a program to:
   - Quantify and understand the Polar Front meander, eddy and topography interaction processes to resolve competing hypotheses that govern the strength of the ACC and its response to changes in winds.
   - Our detailed survey of an ACC meander, and the time series that will be captured by the moored instruments left behind, are a world-first that will provide much-needed evidence of the physical processes controlling the ACC.
   - The voyage will help inform Australia's strategy for ocean modelling through improving our process understanding of the role of the Southern Ocean in Earth's climate system, and for providing potential new methods for monitoring the poleward heat fluxes using satellite observations.

PART B -VOYAGE SUMMARY

Voyage Summary

Objectives and brief narrative of voyage

Our voyage provides unique observations of the Antarctic Circumpolar Current (ACC), an immense ocean current that plays an important role in our climate system. There are many questions about how the ACC is changing in response to climate change, and how it will in turn affect our climate. For decades, the winds over the Southern Ocean have been strengthening and yet the strength of the current has not changed. Many theories have been developed to try to explain why this is so but there have been no observations available to test these theories. Our detailed survey of an ACC meander, and the time series that will be captured by the moored instruments left behind, are a world-first that will provide much-needed evidence of the physical processes controlling the ACC. These data will guide the development of new theories and will constrain computer models to the real world and provides the potential for developing methods for monitoring poleward heat-fluxes from satellites.

Scientific objectives

The Antarctic Circumpolar Current (ACC) is a system of eastward flowing jets, standing meanders, and transient eddies that plays a disproportionately large role in climate. Its steeply-sloping density surfaces permits a global-scale overturning circulation that has allowed the ocean to absorb 93% of the long term global warming, 65% of which is taken up in the Southern Ocean in the last two decades, and approximately 26% of anthropogenic carbon dioxide emissions. The ACC is forced at the surface by westerly winds and heat and freshwater fluxes. The Southern Ocean westerlies have been strengthening over the last two decades (by ~20%). Yet the strength of the ACC and the tilt of density surfaces across the current have remained constant. This puzzle is a large gap in our understanding of the ACC response to climate signals, and the ACC's influence or feedback on the global circulation and its continuing uptake of heat and carbon dioxide by the ocean.

Recent numerical studies emphasize the crucial role played by localized standing meanders that occur at only a handful of sites where the ACC encounters rough topography. They indicate that the 'brakes' on the ACC are applied strongly and abruptly in these few locations rather than continuously along the circumpolar ACC. Observations are crucially needed to ground-truth present and future theoretical and numerical modeling developments regarding the ACC.

We will obtain a unique 3-dimensional survey of a standing meander in the ACC, and deliver companion high-resolution simulations, to quantify the processes that slow the ACC. Our observations will extend from the meander-scale processes identified in global models, to the internal wave and turbulence scale that the models do not see, to provide a thorough assessment of the meander-eddy-wave-topography interactions that make the ACC insensitive to increasing wind strength.

All investigators share the common objectives.

Voyage objectives

We will combine a full-depth CTD/LADCP and bathymetric survey of the full meander, with targeted, rapid underway sampling of smaller-scale variability using the Triaxus towed CTD, a VMP-2000 microstructure profiler and underway instruments. Multi-beam data will be important for interpreting the survey data. Water samples will be analysed for nutrients, chlorophyll and particulate organic carbon (POC). Incubation experiments will be conducted to observe phytoplankton productivity under varying physical and chemical conditions.

Objectives

1. **Deployment of a fleet of EM-APEX profiling floats.**
2. **Deployment of a tall mooring** at the crest of a meander in the Polar Front of the Antarctic Circumpolar Current.
3. **Full-depth hydrographic survey** of the physics and biogeochemistry of the targeted ACC meander, conducting transects across the front. This will include CTD/LADCP profiles, water sample analysis, VMP-2000 microstructure profiles, bathymetry and underway instruments.
4. **Triaxus transects.** These will include transects across and along the front and transects around the mooring.

Results

The results from our voyage exceeded our expectations. Our voyage required flexibility in planning as we were surveying a very dynamic part of the ocean. The ACC meander and eddies that were the focus of our voyage move rapidly and unpredictability. Our strategy was to redefine our sampling plan each day according to the daily updating satellite maps of sea surface height showing the latest path of the current. Our moving sampling plan was accommodated by the Master, Voyage Manager and ship's crew with interest, understanding and patience. We are very grateful for their contributions to our voyage achievements.

1. *Deployment of a fleet of EM-APEX profiling floats.*

   Six EM-APEX were deployed, along with 10 surface drifters provided by NOAA, to map the variations in the temperature, salinity and velocity structure within the meander and beyond. By the end of their battery life, the EM-APEX will have provided more than 2000 profiles covering a distance of around 3000 km along the ACC. The floats passed through many different regimes along their paths, sampling smooth currents and energetic eddies, south and north of the Polar Front, passing over smooth/rough and shallow/deep bathymetry, and even navigating a narrow passage to cross the Macquarie Ridge. This is an extraordinary dataset that will provide the foundation for new insights into eddy-meander dynamics in the ACC.

2. *Deployment of a tall mooring at the crest of a meander in the Polar Front of the Antarctic Circumpolar Current.*

   The mooring deployment was successfully completed at the beginning of the voyage. The mooring will be recovered in March/April 2020 on IN2020_V02 (Coffin).

3. *Full-depth hydrographic survey of the physics and biogeochemistry of the targeted ACC meander, conducting transects across the front. This will include CTD/LADCP profiles, water sample analysis, VMP-2000 microstructure profiles, bathymetry and underway instruments.*

   Figure 1 shows the arrangement of the CTD transects (blue dashed lines and pink crosses) with Triaxus transects in between. The sea surface height map shown is at the end of the voyage and is useful to understand the movement of the EM-APEX floats and drifters on that day. It does not, however, illustrate the evolution of the meander during the voyage (we are developing a movie to do that). Each CTD transect was designed to be perpendicular to the path of the Polar Front on the day it was crossed. After the first few transects on the western side, the meander crest and trough steepened and eddies began to form. We maintained our focus on the core of the front as there was not sufficient time to explore the eddy field. We obtained 77 full-depth CTD/LADCP casts with full hydrochemistry along 9 cross-front transects. At 47 of the CTD stations we obtained microstructure turbulence profiles to 1500 m depth using the VMP-2000 provided and operated by Kurt Polzin, WHOI.

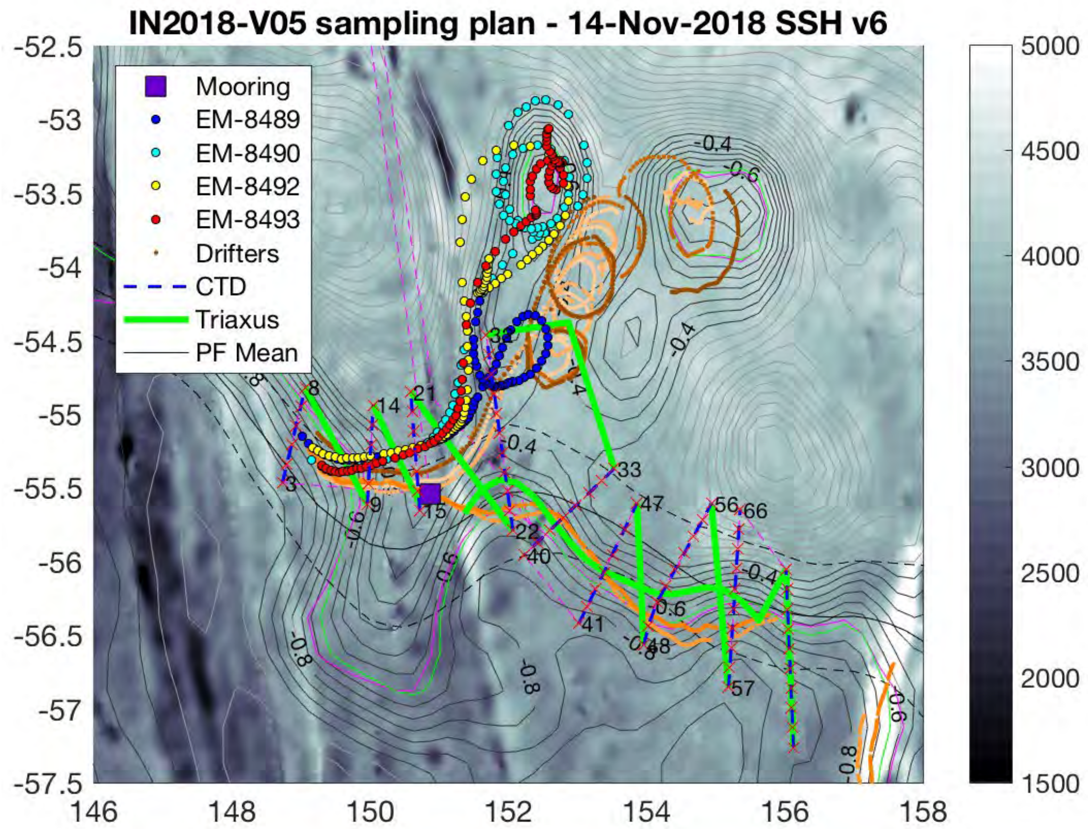


Figure 1. Sampling completed during IN2018_V05. Locations occupied for each instrument as shown in the legend. CTD stations are marked by a pink cross. Shading indicates the water depth based on Smith and Sandwell bathymetry (m). Pink dashed line is ship's track. Contours are sea surface height (m) from AVISO satellite altimetry, with dark contours indicating the location of the Polar Front. Smooth black line with dashed envelope marks the mean position of the Polar Front core in the altimetry record, and SSH contours highlighted pink and green show the position of the core on the day of the satellite map from two methods. Each CTD transect was perpendicular to the Polar Front at the time that the transect was made. Triaxus transects (green) provided high-resolution profiling of the upper 300 m and provided intermediate crossings of the front between CTD transects.

4. *Triaxus transects. These will include transects across and along the front and transects around the mooring.*

   The favourable conditions, chosen as breaks between weather fronts, and excellent technical team allowed us to tow the Triaxus, with 0-300 m undulations, back and forth across the front for a total of 626 km along a total of 8 transects. The final Triaxus tow at the end of the last CTD transect, as we worked back through the survey region to fill in gaps in the multibeam bathymetry, provided a unique along-stream view within the core of the Polar Front. The Triaxus provided detailed upper ocean data between CTD transects, and is an incredible resource to investigate air-sea interaction, as well as the physical and biogeochemical process in the mixed layer and at the interface between surface waters and Circumpolar Deep Water.

Voyage Narrative

The following tables provide the position and times of each set of measurements in the order in which they happened. These include the test CTD/VMP station, the mooring deployment, 9 CTD/LADCP transects (77 stations of which 47 had collocated VMP-2000 microstructure profiles), 8 Triaxus legs (7 across-front, 1 along-front), 6 EM-APEX and 10 surface drifter deployments. Mulit-beam bathymetry data collected during our survey revealed a number of interesting features that we were able to re-visit to fill in missing pieces in conjunction with the along-front Triaxus tow back toward the mooring site. The locations of 4 features are shown below.

For information on the weather conditions and the successes and challenges faced during the voyage, please see the table of weather and daily activities in Appendix B. Detailed reports on mooring and VMP-2000 operations are provided in Appendix C (Mooring) and Appendix D (VMP-2000).

Hobart to test site

Test CTD/VMP

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 1 – Test	2018-10-16 21:42	2018-10-17 00:37	-45.8615	148.7089	4275.3
VMP 1 – Test	2018-10-17 21:42		-49.8396	149.3595	

Mooring

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 2	2018-10-19 12:47	2018-10-19 16:15	-55.5482	150.8463	3645.3
Mooring deployment	See below for anchor release time and final position from triangulation				
VMP 2 – 3 dips	2018-10-20 06:15		-55.5606	150.7957	

Final deployment data from triangulation of acoustic releases are shown here. See Appendix C for the complete and authoritative Mooring Report.

Triangulated landing site latitude	55° 32.544'S
Triangulated landing site longitude	150° 52.332'E
Bottom depth	3620 m
Depth of top of mooring	120 m

Anchor release date (UTC)	2018-10-20
Anchor release time (UTC)	02:23
Sound speed for triangulation from CTD	1484.5 m/s
Anchor dragback	1213 m towards 127°

To start of survey

CTD Transect 1

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 3	2018-10-20 16:43	2018-10-20 20:02	-55.4838	148.7151	3505.8
CTD 4	2018-10-20 21:36	2018-10-21 00:55	-55.3392	148.8035	3602.1
CTD 5 Followed by deployments of EM-APEX 8490 Drifter 512690 EM-APEX 8493 Drifter 613490	2018-10-21 02:28 2018-10-21 06:53	2018-10-21 05:56	-55.2117 -55.2070	148.8660 148.8712	3691.5
CTD 6 Followed by deployments of EM-APEX 8492 Drifter 512670 EM-APEX 8489 Drifter 613530	2018-10-21 08:14 2018-10-21 12:00	2018-10-21 11:45	-55.0985 -55.0975	148.9126 148.9128	3748.9
CTD 7 Followed by deployments of EM-APEX 8491 Drifter 613550 EM-APEX 8494 Drifter 512730	2018-10-21 13:24 2018-10-21 17:34	2018-10-21 17:12	-54.9709 -54.9677	149.0139 149.0050	3912.7
CTD 8 (VMP)	2018-10-21 19:43	2018-10-21 23:32	-54.8828	149.1876	3920.3

Triaxus Leg 1

- 56 km of undulating profiles between CTD 8 and CTD 9 crossing the Polar Front towards the southeast

CTD Transect 2

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)

CTD 9 (VMP)	2018-10-22 14:36	2018-10-22 17:55	-55.6026	149.9659	3842.6
CTD 10 (VMP)	2018-10-22 19:07	2018-10-22 22:26	-55.4775	150.0566	3840.1
CTD 11	2018-10-23 01:11	2018-10-23 04:16	-55.3525	150.0465	3662
CTD 12 (VMP)	2018-10-23 05:49	2018-10-23 09:08	-55.2268	150.0600	3888.8
CTD 13 (VMP)	2018-10-23 12:30	2018-10-23 15:42	-55.1095	150.0978	3912
CTD 14	2018-10-23 18:55	2018-10-23 22:14	-54.9723	150.1883	3683.1

Triaxus Leg 2

- 46 km of undulating profiles between CTD 14 and CTD 15 crossing the Polar Front towards the southeast

CTD Transect 3

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 15 (VMP)	2018-10-24 09:43	2018-10-24 12:55	-55.6574	150.7628	3816.6
CTD 16 (VMP)	2018-10-24 15:56	2018-10-24 19:25	-55.5332	150.6727	3984.1
CTD 17 (VMP)	2018-10-24 22:35	2018-10-25 01:58	-55.4024	150.7497	3803.9
CTD 18	2018-10-25 05:13	2018-10-25 08:54	-55.3061	150.7381	3814.5
CTD 19	2018-10-25 12:24	2018-10-25 15:43	-55.1308	150.6901	3729.5
CTD 20 (VMP)	2018-10-25 18:25	2018-10-25 21:48	-54.9930	150.7582	3663.9
CTD 21 (VMP)	2018-10-26 02:21	2018-10-26 05:45	-54.8659	150.7128	3805.7

Triaxus Leg 3

- 75 km of undulating profiles between CTD 21 and CTD 22 crossing the Polar Front towards the southeast

CTD Transect 4

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 22 (VMP)	2018-10-26 20:14	2018-10-26 23:17	-55.7928	152.1425	3646.2
CTD 23 (VMP)	2018-10-27 02:09	2018-10-27 05:36	-55.6655	152.0773	3879.2
CTD 24 (VMP)	2018-10-27 08:32	2018-10-27 11:40	-55.5049	152.0275	3594.3
CTD 25 (VMP)	2018-10-27 14:15	2018-10-27 17:26	-55.4021	151.9561	3553.3

CTD 26 (VMP)	2018-10-27 20:13	2018-10-27 22:53	-55.2509	151.9141	2856.3
CTD 27 (VMP)	2018-10-28 01:13	2018-10-28 04:38	-55.1267	151.8741	3745.7
CTD 28	2018-10-28 07:09	2018-10-28 10:24	-55.0035	151.8411	3735.8
CTD 29	2018-10-28 11:48	2018-10-28 14:56	-54.8625	151.7974	3522
CTD 30	2018-10-28 16:05	2018-10-28 20:14	-54.7251	151.8033	3905.8
CTD 31 (VMP)	2018-10-28 21:25	2018-10-29 00:47	-54.5777	151.7812	3839.2
CTD 32 (VMP)	2018-10-29 03:18	2018-10-29 06:49	-54.4367	151.7600	4040.2

Triaxus Leg 4

- 84 km of undulating profiles across the cold-core centre of the Polar Front meander trough
- from CTD 32 to the centre of the cold core at 54.3763 S, 152.8724 E moving to the east and then to CTD 33 moving to the southeast

CTD Transect 5

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 33	2018-10-30 02:53	2018-10-30 06:30	-55.3754	153.5068	3991.5
CTD 34 (VMP)	2018-10-30 07:46	2018-10-30 11:18	-55.4825	153.3512	3846.9
CTD 35 (VMP)	2018-10-30 13:44	2018-10-30 17:03	-55.5717	153.1736	3846
CTD 36 (VMP) Followed by deployments of Drifter 513430 Drifter 512710	2018-10-30 19:52 2018/10/31 00:50	2018-10-30 23:21	-55.6513 -55.6667	153.0193 153.0385	3927.7
CTD 37	2018-10-31 01:52	2018-10-31 05:10	-55.7050	152.8431	3780.5
CTD 38 Followed by deployments of Drifter 512720 Drifter 513580	2018-10-31 06:43 2018-10-31 10:32	2018-10-31 10:24	-55.7991 -55.7993	152.6757 152..6770	3839.9
CTD 39	2018-10-31 12:06	2018-10-31 14:59	-55.8881	152.4753	2918.9
CTD 40 (VMPx2)	2018-10-31 16:24	2018-10-31 19:40	-55.9662	152.2631	3828.6

CTD Transect 6

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)

CTD 41 (VMP)	2018-11-01 05:29	2018-11-01 08:40	-56.4038	153.0988	3683.6
CTD 42 (VMP)	2018-11-01 10:57	2018-11-01 14:05	-56.3041	153.2085	3716.9
CTD 43 (VMP)	2018-11-01 16:27	2018-11-01 19:29	-56.2081	153.3272	3728.2
CTD 44 (VMP)	(VMP)2018-11-01 22:01	2018-11-02 01:00	-56.0649	153.3991	3610.3
CTD 45 (VMP)	2018-11-02 03:09	2018-11-02 06:31	-55.9636	153.6305	3693.8
CTD 46 (VMP)	2018-11-02 12:22	2018-11-02 15:41	-55.7808	153.7269	3706.4
CTD 47 (VMP)	2018-11-02 18:31	2018-11-02 21:50	-55.6374	153.8905	3798.7

Triaxus Leg 5

- 58 km of undulating profiles between CTD 47 and CTD 48 crossing the Polar Front from north to south

CTD Transect 7

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 48 (VMP)	2018-11-03 11:12	2018-11-03 14:23	-56.6017	153.9567	3656.9
CTD 49	2018-11-03 15:40	2018-11-03 18:47	-56.4692	154.0584	3655.8
CTD 50	2018-11-03 20:11	2018-11-03 23:18	-56.3023	154.1867	3623.8
CTD 51 (VMP)	2018-11-04 00:29	2018-11-04 03:30	-56.1800	154.3310	3699.8
CTD 52 (VMP)	2018-11-04 05:57	2018-11-04 09:21	-56.0913	154.5126	3834.1
CTD 53	2018-11-04 12:14	2018-11-04 15:24	-55.9700	154.6336	3897.4
CTD 54	2018-11-04 16:30	2018-11-04 19:50	-55.8527	154.7444	4108.6
CTD 55	2018-11-04 21:04	2018-11-05 00:24	-55.7181	154.8180	4232.9
CTD 56 (VMPx3)	2018-11-05 01:44	2018-11-05 05:14	-55.6307	154.9271	4305.6

Triaxus Leg 6

- 75 km of undulating profiles between CTD 56 and CTD 57 crossing the Polar Front from north to south

CTD Transect 8

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)

CTD 57 (VMPx2)	2018-11-05 23:15	2018-11-06 02:17	-56.8803	155.2240	3703.5
CTD 58 (VMP)	2018-11-06 03:20	2018-11-06 06:32	-56.7319	155.1915	3729.3
CTD 59 (VMP)	2018-11-06 09:07	2018-11-06 12:15	-56.5970	155.2413	3652.1
CTD 60 (VMP)	2018-11-06 14:31	2018-11-06 17:36	-56.4713	155.2645	3739.5
CTD 61 (VMP)	2018-11-06 20:07	2018-11-06 23:34	-56.3632	155.3692	3878.5
CTD 62 (VMP)	2018-11-07 02:35	2018-11-07 05:55	-56.2288	155.4044	3885
CTD 63 (VMPx3)	2018-11-07 08:59	2018-11-07 12:22	-56.0805	155.4150	3949.3
CTD 64	2018-11-07 13:50	2018-11-07 17:11	0.0000	155.4072	4216.9
CTD 65	2018-11-07 18:59	2018-11-07 22:17	-55.8309	155.4342	3848.7
CTD 66	2018-11-08 00:03	2018-11-08 03:23	-55.6894	155.3987	3993.2

First CTD station on Transect 9 completed and then decided to do VMP and Triaxus work while we had a good weather window.

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 67	2018-11-08 06:29	2018-11-08 09:59	-56.0674	156.1051	4031.1
VMP 44	2018-11-08 22:06	2018-11-08 23:17	-56.8633	156.1555	
VMP 45 – 2 casts	2018-11-08 23:44	2018-11-08 01:51	-56.9013	156.1855	

Triaxus Leg 7

- 72 km of undulating profiles between CTD 66 and CTD 67 crossing the Polar Front from north to south

CTD Transect 9

Event	Start Date/Time (UTC) yyyy-mm-dd hour:min	End Date/Time (UTC) yyyy-mm-dd hour:min	Start Lat (decimal degrees)	Start Lon (decimal degrees)	Water Depth at start (m)
CTD 68 (VMP)	2018-11-09 08:47	2018-11-09 11:42	-57.2709	156.0934	3479.4
CTD 69 (VMP)	2018-11-09 14:08	2018-11-09 17:09	-57.1330	156.1055	3523.8
CTD 70	2018-11-09 19:31	2018-11-09 22:45	-57.0129	156.0964	3893.9
CTD 71	2018-11-10 00:54	2018-11-10 03:59	-56.8747	156.0780	3820.3
CTD 72	2018-11-10 05:05	2018-11-10 08:20	-56.7479	156.0577	3872.3
CTD 73	2018-11-10 09:26	2018-11-10 12:33	-56.5980	156.0687	3688.1
CTD 74	2018-11-10 13:39	2018-11-10 16:43	-56.4763	156.0546	3719.7
CTD 75	2018-11-10 18:25	2018-11-10 21:27	-56.3702	156.1685	3808.1

CTD 76	2018-11-10 23:10	2018-11-11 02:25	-56.2139	156.1941	4009.1
CTD 77	2018-11-11 04:01	2018-11-11 07:16	-56.0778	156.1767	3925.4

Triaxus Leg 8

- 158 km of undulating profiles from CTD 77 southwestward to the core of the Polar Front and from there following the path of the core from east to west back through the CTD survey (interrupted due to weather and restarted)
- The purpose of this transect was to
    i. provide an along-stream view of the upper ocean temperature, salinity, biogeochemistry and velocity structure to complement the primarily cross-stream view obtained with the CTD transects and other Triaxus surveys; and
    ii. fill in the gaps in multibeam bathymetry .

Survey of interesting bathymetric features

Feature ID	Name	Latitude	Longitude
A	Guyot	-55.773735	152.343143
B	Seamount 1	-55.320765	151.728210
C	Seamount 2	-55.045472	151.218651
D	Ridge	-54.904677	150.932385

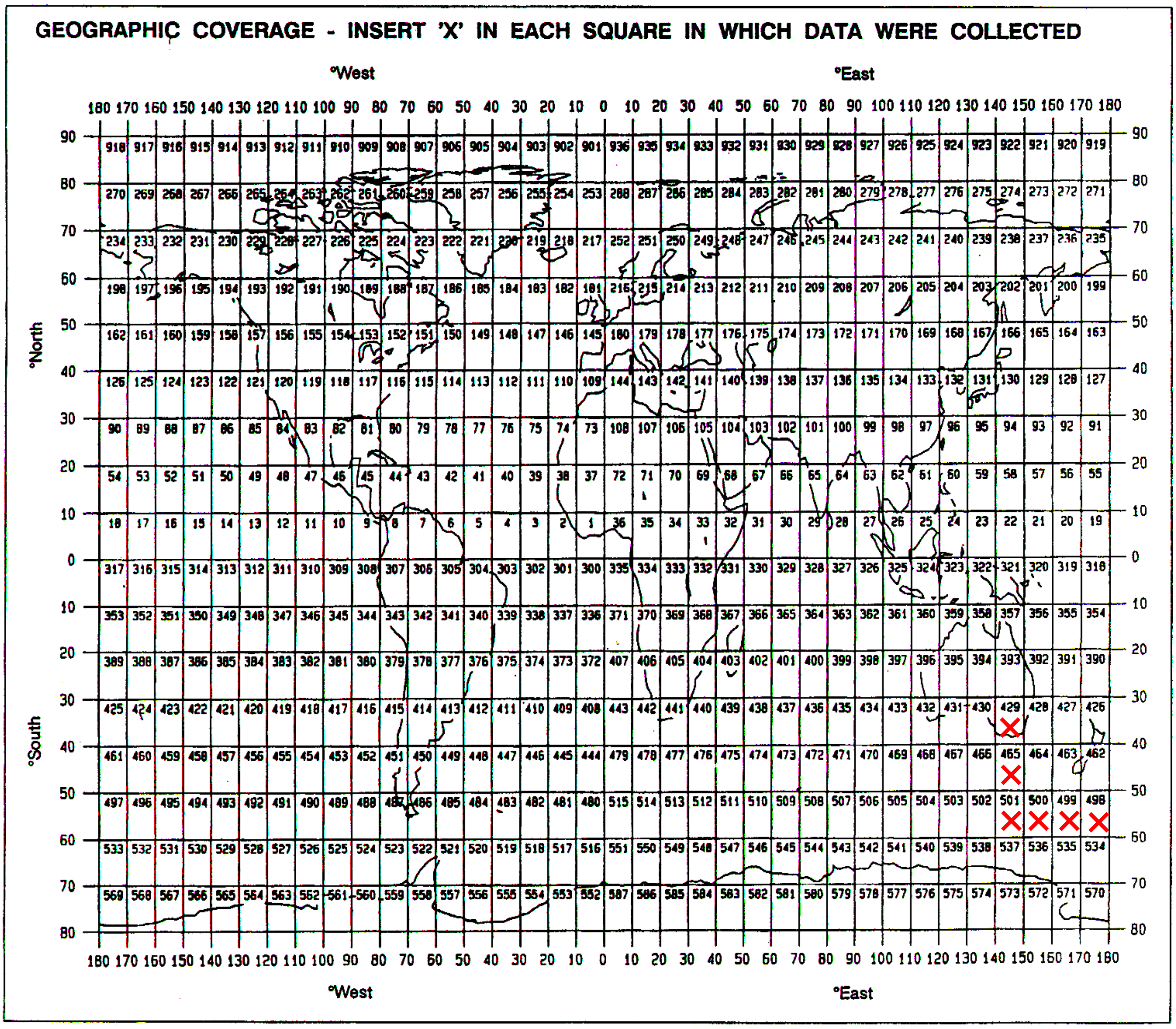
Departed survey area 2018-11-12 14:19 at -54.8910, 150.9272 and headed north on a track slightly offset from the inbound track in order to pass over uncharted bathymetry.

Summary

This voyage delivered a world first by observing the velocity and density structure of a full meander in the ACC in a region where interaction with bathymetry appears to control the current's response to increasing Southern Ocean winds. We were very fortunate with the weather and were able to complete all of the planned work. Each of the data streams will lead to new insights into the role of the Southern Ocean in the climate system. The synthesis of observations with the high-resolution numerical model will be an outstanding contribution to understanding ACC dynamics. There is also potential for developing methods for monitoring poleward heat-fluxes from satellites through the development of empirical measures of this transport. The results will also provide a pathway to improved climate predictions through better representation of physicals processes in ocean models in the important regions for climate change.

Marsden Squares

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



Moorings, bottom mounted gear and drifting systems

Item No	PI See page above	APPROXIMATE POSITION						DATA TYPE enter code(s) from list on last page	DESCRIPTION
		LATITUDE			LONGITUDE				Identify, as appropriate, the nature of the instrumentation the parameters (to be) measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any identifiers given to the site.
		deg	min	N/S	deg	min	E/W		
1	All	55	32.544	S	150	52.332	E	H10, H72, D01, D71, D90 (moored CTD)	Mooring Deployment – temperature, salinity, pressure (microCAT sensors), horizontal velocity (point measurements and profiling ADCP)
2	All	55	12.288	S	148	52.166	E	D05	Surface Drifter – #300234065512690 (for NOAA Global Drifter Program)
3	All	55	11.658	S	148	51.809	E	D05	Surface Drifter - #300234065613490
4	All	55	5.598	S	148	55.149	E	D05	Surface Drifter - #300234065512670
5	All	55	5.191	S	148	55.781	E	D05	Surface Drifter - #300234065613530
6	All	54	58.064	S	149	0.298	E	D05	Surface Drifter -#300234065613550
7	All	54	57.827	S	148	59.767	E	D05	Surface Drifter - #300234065512730
8	All	55	47.960	S	152	40.620	E	D05	Surface Drifter - #300234065512720
9	All	55	47.980	S	152	40.390	E	D0	Surface Drifter - #300234065613580
10	All	55	40.024	S	153	2.193	E	D05	Surface Drifter - #300234065512710
11	All	55	39.999	S	153	2.308	E	D05	Surface Drifter - #300234065613430
12	All	55	12.420	S	148	52.272	E	H10/H11, D71	EM-APEX 8490 - enhanced Argo float that also measures current speed and direction (temperature, salinity, pressure , horizontal velocity)
13	All	55	11.778	S	148	51.918	E	H10/H11, D71	EM-APEX 8493 (temperature, salinity, pressure , horizontal velocity)
14	All	55	5.850	S	148	54.768	E	H10/H11, D71	EM-APEX 8492 (temperature, salinity, pressure , horizontal velocity)
15	All	55	5.191	S	148	55.781	E	H10/H11, D71	EM-APEX 8489 (temperature, salinity, pressure , horizontal velocity)

Item No	PI See page above	APPROXIMATE POSITION						DATA TYPE enter code(s) from list on last page	DESCRIPTION Identify, as appropriate, the nature of the instrumentation the parameters (to be) measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any identifiers given to the site.
		LATITUDE			LONGITUDE				
		deg	min	N/S	deg	min	E/W		
16	All	54	58.064	S	149	0.298	E	H10/H11, D71	EM-APEX 8491 (temperature, salinity, pressure , horizontal velocity)
17	All	54	57.827	S	148	59.767	E	H10/H11, D71	EM-APEX 8494 (temperature, salinity, pressure , horizontal velocity)

Summary of Measurements and samples taken

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
1	All	626	km	H11 H16 H17	Triaxus undulating towed body transits across the Polar Front between 10 and 300m depth. Sensors : pressure, temperature, conductivity, dissolved oxygen, PAR, 700nm beam transmission, chlorophyll fluorescence, backscatter, laser optical plankton counter, SUNA ultra-violet spectrometric nitrate analyser.
2	All	77	profiles	H10 H11, H16, H17, D71, H21, B02	CTD Profiles – temperature, salinity, pressure, dissolved oxygen, transmissometer, PAR, fluorescense, lowered ADCP
3	All	77	profiles	H10 H22, H25, H26, H75, H76, B02	CTD Stations – 36 bottle rosette with 12l Niskins
4	All	32	days	H71	Underway thermosalinograph
5	All	32	Days	D71	Underway shipboard ADCP – 150kHz and 75kHz installed on drop keel (6m below water line), narrowband mode. See ADCP Data Processing report for information about data collection and quality problems.
6	All	32	Days	M06	Routine underway Meteorology
7	All	32	Days	G73, G74, G27	Underway geophysics – EK60 Echosounder, EM122 Multibeam, EM710 Mk II Multibeam, Gravity, SBP120 Sub-bottom profiler
8	All	6 1786	Floats Profiles	H10/H11, D71	EM-APEX Profiling Floats (Hull numbers 8489, 8490, 8491, 8492, 8493, 8494) – measured temperature, salinity, pressure, horizontal velocity direction and magnitude. Only 4 of the 6 floats reported after deployment.; floats 8491 and 8494 never transmitted after they were deployed in spite of reporting reliably during on shore and pre-deplloyment testing). At the end of March we had 1786 profiles, 3 floats were still reporting but 8492 had stopped reporting on 24th Feb 2019.
9	All	8	Drifters	D05	NOAA Surface Drifters – position, surface temperature and pressure

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate, e. g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
10	All	1	Profile	H13	XBT – 1 deployment only – to get a sound speed profile on return transit

Track Chart

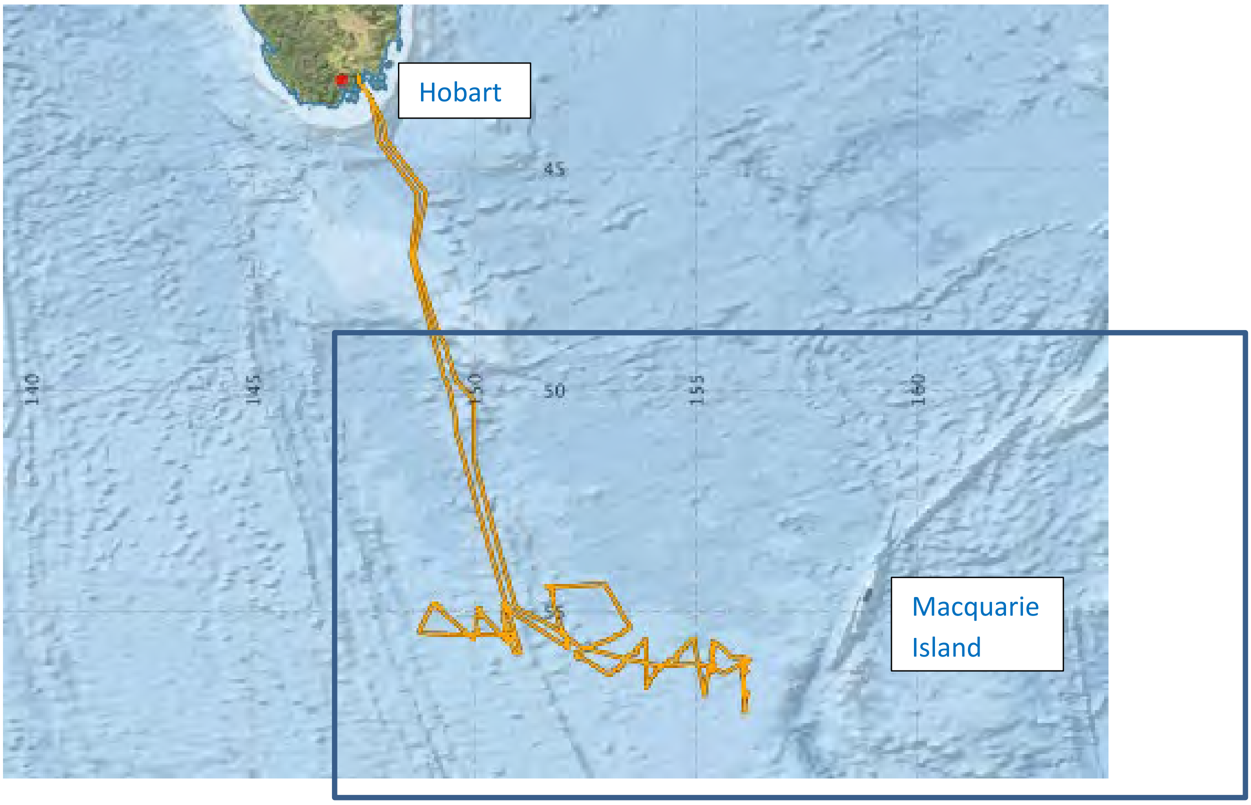


Figure 2. Complete voyage track from Hobart to Hobart. Box indicates the approximate region covered in Figure 2.

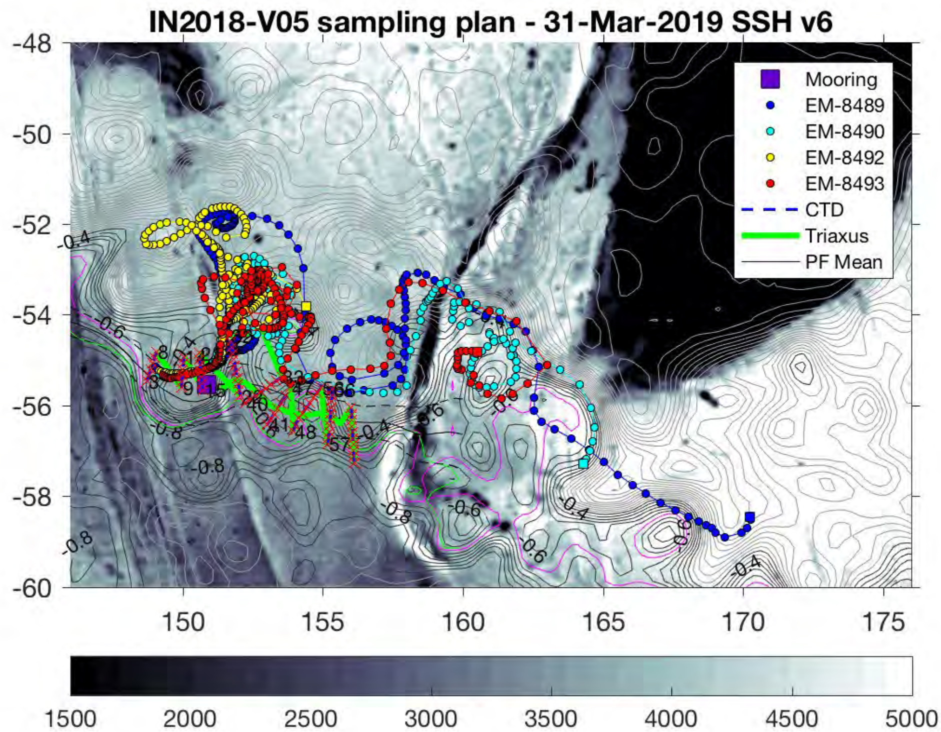


Figure 3. Detail of location of observations by the primary instruments used: CTD/LADCP, EM-APEX, Triaxus. Sea surface height contours are shown for 31st March at the time of the latest EM-APEX profiles. Dark contours are those located in the Polar Front. The smooth black contour and dashed black envelope indicate the mean and standard deviation of the Polar Front core from the full altimetric record.

Acknowledgements

Signature

Your name	Prof Nathan Bindoff and Dr Helen Phillips
Title	Chief Scientists
Signature	
Date:	25th April 2019

List of additional figures and documents

Appendix A CSR/ROSCOP Parameter CodeS

Appendix B Summary of weather and daily activities

Appendix C Mooring report – Mark Rosenberg (ACE-CRC) and Jamie Derrick (CSIRO)

Appendix D VMP report – Kurt Polzin (WHOI)

Appendix E Photographs

Appendix A - CSR/ROSCOP Parameter CodeS

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

	PHYSICAL OCEANOGRAPHY
H71	Surface measurements underway (T,S)
H13	Bathythermograph
H09	Water bottle stations
H10	CTD stations
H11	Subsurface measurements underway (T,S)
H72	Thermistor chain
H16	Transparency (eg transmissometer)
H17	Optics (eg underwater light levels)
H73	Geochemical tracers (eg freons)
D01	Current meters
D71	Current profiler (eg ADCP)
D03	Currents measured from ship drift
D04	GEK
D05	Surface drifters/drifting buoys

	MARINE BIOLOGY/FISHERIES
B01	Primary productivity
B02	Phytoplankton pigments (eg chlorophyll, fluorescence)
B71	Particulate organic matter (inc POC, PON)
B06	Dissolved organic matter (inc DOC)
B72	Biochemical measurements (eg lipids, amino acids)
B73	Sediment traps
B08	Phytoplankton
B09	Zooplankton
B03	Seston
B10	Neuston
B11	Nekton
B13	Eggs & larvae
B07	Pelagic bacteria/micro-organisms
B16	Benthic bacteria/micro-organisms
B17	Phytobenthos
B18	Zoobenthos
B25	Birds
B26	Mammals & reptiles
B14	Pelagic fish
B19	Demersal fish
B20	Molluscs
B21	Crustaceans

D06	Neutrally buoyant floats
D09	Sea level (incl. Bottom pressure & inverted echosounder)
D72	Instrumented wave measurements
D90	Other physical oceanographic measurements

	CHEMICAL OCEANOGRAPHY
H21	Oxygen
H74	Carbon dioxide
H33	Other dissolved gases
H22	Phosphate
H23	Total - P
H24	Nitrate
H25	Nitrite
H75	Total - N
H76	Ammonia
H26	Silicate
H27	Alkalinity
H28	PH
H30	Trace elements
H31	Radioactivity
H32	Isotopes
H90	Other chemical oceanographic measurements

B28	Acoustic reflection on marine organisms
B37	Taggings
B64	Gear research
B65	Exploratory fishing
B90	Other biological/fisheries measurements

	MARINE GEOLOGY/GEOPHYSICS
G01	Dredge
G02	Grab
G03	Core - rock
G04	Core - soft bottom
G08	Bottom photography
G71	In-situ seafloor measurement/sampling
G72	Geophysical measurements made at depth
G73	Single-beam echosounding
G74	Multi-beam echosounding
G24	Long/short range side scan sonar
G75	Single channel seismic reflection
G76	Multichannel seismic reflection
G26	Seismic refraction
G27	Gravity measurements
G28	Magnetic measurements
G90	Other geological/geophysical measurements

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

Appendix B – Summary of weather and activities

Daily summary of activities on IN2019_V05.

Date (AEST)	Position	Wind Direction Speed (knots)	Seas Direction Height (feet)	Comments
16/10/18	Depart Hobart			
18/10/18	50-12.5S 144-28.7E	ESE 11-16 kt	SSW 6-8 ft	Toolbox meetings for CTD and user supplied VMP followed by test deployments of both.
19/10/18	54-43.5S 150-40.8E	NW 11-16 kt	WSW 4-6 ft	In transit to mooring site. Weather cold and damp. Weather conditions are going to be tight for the mooring deployment tomorrow with the wind backing from the north to the west very quickly in the early afternoon and unfavourable conditions for the next few days afterwards. Plan to start mooring operations at 6am
20/10/18	55-34.1S 150-51.2E	NW 22-27 kt	WSW 4-6 ft	Arrived at mooring location at 1800 last night and began swath map survey of bathymetry. CTD in the water at 2327 but had to be recovered due to technical issue. Problem solved quickly and full depth CTD to 3951 m completed. Cancelled VMP to start mooring operations at daybreak. Mooring operations started at 0555, first float in the water at 0629. Deployment went smoothly and anchor released at 1323. Plan is to complete triangulation of mooring position and then do VMP cast that was skipped this morning. Apart from drizzle, fog and cold the weather remains fine in spite of the forecast.
21/10/18	55-20.3S 148-48.2E	NNW 28-33 kt	NNW 12-16 ft	Mooring triangulation was successfully completed at 1615 yesterday. VMP proved problematic. First deployment attempted at 1639 with a nominal wire out of 2000m. Recovery was difficult due to repeated tripping out of the custom winch. Finally recovered at 1857. Possible that the power converter from ship's 415V/50Hz power to 480V/60Hz power required by the US winch isn't up to the job. May have to fall back to deploying the VMP using the ship's light sediment winch. Deck secured and underway to the first survey line by 1740. After a full depth cast to 3506m the CTD was back on deck at 0702 and we were underway for the next station at 0705. Ship was on station at 0828, CTD was in the water at 0842 and back on deck at 1202. Weather is continuing to deteriorate but at the moment we've deployed the CTD again and will assess

				the conditions for further deployments as the night goes on
22/10/18	54-54.7S 149-14.7E	NNW 17-21 kt	NNW 4-8 ft	CTD station 5 to 3690m completed at 1649. Two EM-APEX floats and 2 surface drifters were successfully deployed at 1754 in high, confused seas from the main deck aft though not without some wet feet. Arrived CTD station 6 at 1905. CTD completed by 2247. Two more EM-APEX floats and 2 surface drifters deployed at 2301 as we departed the station. CTD in the water at station 7 at 0036. CTD went to full depth at 3913m and was recovered at 0412. Two more APEX floats and 2 surface drifters were deployed as we departed the station. Ship arrived at station 8 at 0610 and the CTD was deployed at 0646 to a depth of 4300m. CTD was back on deck at 1031 and the VMP-2000 was deployed over the side using the light sediment winch. This worked reasonably well except that the line is more buoyant and instrument fall rate is reduced. First Triaxus survey line is scheduled for this afternoon.
23/10/18	55-21.1S 150-00.4E	NW 28-33 kt	NW 8-12 ft	VMP recovered at 1238 followed by transit to the last station on the transect. Triaxus went in the water at 1414 for a 59nm tow to the start of the next CTD transect. Station 9 – VMP followed by CTD Station 10 – CTD followed by VMP First real sunshine since we left Hobart. Underway to Station 11 by noon.
24/10/18	55-06.5S 150-12.5E	WSW 28-33 kt	WSW 8-12 ft	Station 11 – CTD Station 12 – CTD followed by VMP Station 13 – CTD followed by VMP Station 14 – CTD Wind had increased enough to forego another VMP so prepared to start the Triaxus tow. Triaxus deployed at 1024 for a 59nm tow. Science and operations teams are in a smooth routine now.
25/10/18	55-23.8S 150-43.5E	NW 28-33 kt	NW 10-14 ft	Continuing Triaxus tow between CTD transects 2 3 and 3. Triaxus had a technical issue and needed to be recovered at 1415. Electronics technician replaced a connector and triaxus redeployed at 1515. Completed tow at 1858. CTD 15 deployed at 1953 after a short transit. Had to be recovered to check on a faulty oxygen sensor. Redeployed and completed successful profile to 3800m. VMP cast completed at 0140. Station 16 – CTD followed by VMP. Station 17 – CTD followed by VMP.

				Weather returned to cold and rainy. Weather is very predictable here: low pressure and ridge pass by to be followed by another set; repeat. All well on board except for one of the science party with persistent case of mild seasickness and occasional nausea.
26/10/18	54-56.2S 150-56.2E	SSW 7-10 kt	SSW 4-6 ft	CTD 17 completed at 1258, VMP at 1438. Arrived at Station 18 at 1610 and CTD completed at 1626. Modification of the WHOI winch for the VMP was completed by the ship's electrican and chief engineer, and tested with a dumb weight being deployed to 600 m. VMP continued on the sediment winch for this cast but had to be cancelled due to wire tangling. VMP recovered at 2119 and ship underway to Station 19. Got underway to Station 20. CTD 20 in the water at 0530. VMP successfully completed using WHOI winch. Dr Polzin is much happier with the results using his own wire and winch. Got underway to station 21 on port drive. Starboard drive brought back on-line at 1320 thanks to engineers tireless efforts. Weather remains fine.
27/10/18	55-47.1S 152-09.6E	SSW 22-27 kt	SSW 6-8 ft	Arrived on Station 21 at 1313. Full depth CTD to 3760m was followed by a VMP. Repositioned for the start of a Triaxus tow. Triaxus launched at 1927 for a 70 nm tow. Triaxus recovered at 0627 before repositioning on Station 22 for a CTD. CTD 22 and VMP successfully completed. Underway to Station 23. Weather has changed from blowing snow this morning at 0630 to blue sky at noon. Still cold but operations going smoothly.
28/10/18	55-08.9S 151-52.8E	NNW 28-33 kt	NNW 10-14 ft	CTD 23 in the water at 1314 and back on deck at 1642. VMP completed at 2258 and underway to Station 24. Station 24 - CTD and VMP Station 25 - CTD and VMP Station 26 - CTD and VMP Transit to station 27. Respite of blue sky and fine weather has given way to more normal 30 kt westerlies and associated seas as the regular march of low pressure systems continues.
29/10/18	54-34.7S 151-46.8E	WSW 22-27 kt	WSW 8-12 ft	CTD27 deployed at 1218 for a cast to 3750 m. VMP successfully completed and underway to next station at 1710. CTD 28 completed at 2125. Conditions had deteriorated with unfavourable current conflicting with the drift necessary for a safe VMP deployment so the VMP cast was cancelled and we moved on to station 29

				arriving at 2240. CTD29 completed at 0158. Wind and current still unfavourable so VMP cancelled and moved on to Station 30. CTD 30 in the water at 0308. Recovery on deck at 0715. Weather issues at this station again prevented deployment of the VMP. At this point it was more an issue with short, very steep seas posing a risk of damage to the VMP if we tried to deploy it. The VMP has only slight negative buoyancy and more or less drifts away for its sampling so care has to be taken that the instrument and tether is under constant control. At station 31 the weather had improved enough to do a VMP after the CTD. All remains well on board.
30/10/18	55-17.5S 153-29.0E	WSW 22-27 kt	WSW 10-14 ft	CTD32 completed to a depth of 4040 m and recovered at 1750. VMP completed at 1914. After a short transit to the start of a Triaxus deployment, ship was put on course into the weather and Triaxus deployed smoothly at 2023. With the Triaxus on a short leash astern we brought the ship's head around to the east and started to payout the towed body wire to 1500m as we brought the speed up to 7 kts. two-leg Triaxus tow of 100 nm through the top of the meander in the Polar Front. This survey line consisted of two legs of 100 nm total through the top of the meander in the Polar Front. A large following sea made for a slightly energetic ride after we turned to the south at 0300 but it did give the science party and deck crew a short break from the treadmill of CTD and VMP casts.
31/10/18	55-40.4S 153-00.0E	NW 22-27 kt	NW 8-12 ft	Reached the end of the Triaxus survey at 1240. With some careful winch work to account for the somewhat energetic sea and swell the Triaxus was safely back on deck at 1316 after a textbook recovery. Repositioned the ship on station 33 and CTD was in the water at 1359. Sea conditions were not favourable when the CTD came back on deck at 1731 so the VMP was cancelled and moved to the next station. CTD34 completed at 2219. Conditions had improved enough for a VMP, which was completed at 2341. Station 35 – CTD and VMP Station 36 – CTD and VMP Two surface drifters were deployed as we got underway for Station 37.

1/11/18	55-59.7S 152-20.5E	NW 34-40 kt	NW 12-14 ft	CTD 37 to 3780 m was completed at 1610. Weather conditions had deteriorated so cancelled VMP and got underway to Station 38 at 1744. CTD 38 completed at 2124. Conditions were still too severe to do a VMP cast due to its very light nature.Two surface drifters launched as we got underway to Station 39 at 2130. CTD 39 completed at 0200. CTD to 3828 m at Station 40 completed at 0642. We finally had a lull in the weather that allowed a VMP cast at 0654 and we liked it so much that we did two more VMP casts at 0828 and 0953. These extra casts came at a time that allowed a technical issue with the Triaxus to be fixed with the ship on station before we moved onto the start of a Triaxus survey line at 1130. The Triaxus went in the water relatively smoothly in conditions that weren't perfect but were workable. Problems with the trim elevator on Triaxus required it to be recovered at 1223. Conditions had continued to build to a fairly large confused sea causing some concern as to whether we could make a safe recovery at the end of the survey line so the tough decision was made to cancel the tow. Conditions are forecast to remain much the same for the next few days so we'll move onto our next CTD survey line and catch up the Triaxus tows when conditions are safer.
2/11/18	56-03.8S 153-23.9E	ENE 22-27 kt	ENE 6-8 ft	CTD completed at Station 41 at 1941 and a VMP cast followed. Station 42 – CTD and VMP Station 43 – CTD and VMP In transit to Station 44. Operations are going smooth and spirits remain high despite the less than mild sea conditions and weather. Quick breaks in the cloud cover at night have presented some nice auroral displays the last few nights for those up at midnight. The rest of us keep our spirits up with the great meals provided by the caterers.
3/11/18	55-54.4S 153-52.4E	W 17-21 kt	W 6-8 ft	Station 44 – CTD and VMP Station 45 – CTD and VMP Arrived at station 46 at 1956 and CTD was ready to launch but a strong easterly surface current combined with northeasterly winds made a CTD cast difficult. Currents would carry the ship at nearly 2 kts directly to starboard, and bringing the wind far enough off the starboard bow to stop the motion was outside the limit of the engines to hold heading. CTD wire would have quickly lead under the hull. Made the decision

				to move further up the line to give the wind a chance to back further to the north and get us back within the station keeping limits of the ship. New station 46.5 was set midway between 46 and 47 and after a short transit we were on station at 2246. Winds improved and we were able to deploy the CTD. After a full depth cast the rosette was back on deck at 0241 followed by a VMP cast at 0252. On station and CTD 47 in the water at 0537. CTD was back on deck at 0849 and a VMP cast followed a few minutes later. We then got underway to the Triaxus deployment site. There was some time pressure here as conditions are expected to deteriorate considerably during the 10 hour tow to the south. Conditions at the moment are excellent with a blue sky and moderate sea. A good following current should allow us to have the Triaxus back on deck by 1900 tonight while we enjoy a sunny afternoon for a change.
4/11/18	56-10.0S 154-17.4E	W 28-33 kt	W 16-18 ft	Triaxus was recovered at 1929 after a good run in excellent weather. On Station 48 we did a VMP first while the good weather lasted, followed by a CTD to 3660 m, back on deck at 0125. Got underway to Station 49 in less than pleasant conditions. CTD 49 completed at 0548. Conditions were too rough for VMP so headed to Station 50. Completd CTD50 at 0718 in a short, steep sea and decided to cancel the VMP. At 2/3 of the way through the voyage we don't want to lose focus on safe deployments through overconfidence. Arrived at Station 51 after an exciting transit in 16 to 18 foot seas. Being on station is a good respite from the rolling for everyone. CTD 51 was in the water at 1136. The weather will eventually moderate but until then everyone remains motivated to continue sampling as long as we can get the instruments in the water and back on deck again safely.
5/11/18	55-41.4S 154-50.7E	WNW 28-33 kt	WNW 16-18 ft	Station 51 – CTD and VMP Station 52 – CTD and VMP Station 53 – CTD only Weather had deteriorated sufficiently that the next few VMP casts had to be cancelled. Because it only has a slight negative buoyancy the VMP isn't as resilient to launching in heavy seas as the CTD. Although the seas remained high and messy the crew was still able to get the CTD rosette in the water by careful timing of the passing swells. Station 54 – CTD only

				Station 55 – CTD only In transit to Station 56. At the moment we're slightly ahead of schedule with some weather time still available for the final week of the voyage. Morale remains high despite the amount of rough weather we've had the past few weeks. Auroral displays continue to amaze when the cloud cover opens enough to see them.
6/11/18	56-52.5S 155-12.8E	NNW 11-16 kt	NNW 4-8 ft	Station 56 – CTD and 3 VMP casts. The extra VMP casts (to make up for some of the cancellations) were useful for gathering information on how the ocean mixing is changing in time as well as in different locations. It also helped in using up some of the extra time we'd accumulated from the 3 previously cancelled casts and also put us at a better time to start the next Triaxus cast. After a short reposition the Triaxus was launched at 2048 for a 70nm tow overnight. The weather eased overnight, however there was a long-period ground swell up our starboard quarter that kept the ship rolling very deeply until the Triaxus recovery this morning. Not so bad if you were on the night watch, less so if you were trying to sleep. Triaxus was smoothly recovered on deck at 0707, followed by a short transit to station 57. The VMP was deployed first and a dual cast was completed with the instrument recovered at 1002. The CTD was deployed at 1018. The long ground swell is still present but otherwise the weather is excellent.
7/11/18	56-24.1S 155-25.0E	N 17-21 kt	N 8-10 ft	Station 57 – CTD only Station 58 – CTD and VMP Station 59 – CTD and VMP Station 60 – CTD and VMP Station 61 – CTD and VMP In transit to Station 61. CTD casts will continue through the night and tomorrow morning before moving on to a Triaxus tow. Weather conditions are mostly fine for the next few days with just a few short periods of 30 kt winds forecast.
8/11/18	55-39.8S 155-22.3E	SW 37-40 kt	SW 16-18 ft	Station 62 – CTD and VMP CTD 63 was completed at 2324. We remained on station to evaluate whether the VMP could be safely deployed and in the end had to cancel due to unfavourable conditions. Station 64 – CTD only CTD 65 completed at 0915 and decided to try for a VMP cast. The VMP was safely deployed at 0926 but difficulties tracking the wire in the

				rough seas forced us to recover it on deck at 0935 and continue on to station 66. CTD 66 deployed at 1058. This is the final station on the second last CTD survey line and plan A would be to do a Triaxus tow to the final survey line. Conditions remain difficult however and while we believe we can get the Triaxus deployed safe recovery would be very difficult. Our plan now is to continue at full ahead to the final survey line and conduct CTD casts until we can count on a 10-hour stretch of slightly calmer seas to get that Triaxus tow completed. All else is well on board and all personnel are safely wedged into desks, bunks, and tables until we get on station. On the bright side the three hours spent on station for CTD casts are now a break from big rolls during the transits.
9/11/18	56-55.6S 156-11.5E	WNW 22-27 kt	WNW 8-10 ft	CTD 66 to 3993 m completed at 1423. Conditions too rough for VMP or Triaxus. Decided to head straight to the top of the next CTD line (instead of doing a Triaxus tow to the southern end of the line) and continue CTD ops while it's too rough for the Triaxus. Deployed CTD 67 at 1740 after an uncomfortable 3 hour transit. CTD back on deck at 2101 and conditions sufficiently good for a VMP. Weather forecast conditions for Friday had set a window that would allow safe recovery of the Triaxus after an 11-hour tow so that determined our start time for launch. The consecutive VMP casts were done to use that time on station productively. Triaxus made a smooth deployment 0153 and was going well in greatly improved conditions when communications with the sled were lost at 0803. Triaxus was brought back on board at 0837 for troubleshooting and repairs with the goal to redeploy and continue the tow where it had ended. To make use of the time the VMP was rolled out for a cast and in the water at 0907. Casts were continuing at noon while the retermination was completed on Triaxus. Troubleshooting had found a broken optical fibre at the root of the problem. Once the termination is completed we'll redeploy.
10/11/18	56-51.7S 156-05.6E	WNW 22-27 kt	WNW 8-10 ft	Third and final VMP cast completed at 1253 on Station 73. Repairs to the Triaxus were completed ahead of schedule courtesy of hard work by the electronics team. Triaxus was back in the water at 1413. The remainder of the tow

				went well with recovery of the sled at 1912. Repositioned the ship to finish stations on the interrupted final CTD line Station 68 – CTD and VMP Station 69 – CTD and VMP CTD 70 was successfully completed and back on deck at 0943. VMP was deployed at 0950 and then our relaxed Saturday morning was interrupted with a call from the Bridge that the VMP had been lost. There's nothing we can do other than move forward and complete the final 7 CTD casts and Triaxus tows if conditions allow. Following a short transit to station 71 the CTD was back in the water at 1157.
11/11/18	56-11.8S 156-07.0E	W 22-27 kt	W 8-10 ft	CTD casts were completed at Stations 71, 72, 73, 74, 75 and 76. Without the VMP casts at each station we made fairly quick progress along this final CTD survey line. Weather conditions are typical for the area with a steady force 6 winds. Ideally, we'll put the Triaxus in later this afternoon for a 3 to 4 hour tow but at the moment a fairly large ground swell will determine whether we deploy or not. Deployment can be done in relatively rough seas, recovery is much trickier. Regardless of how we spend our remaining science time we'll be underway for Hobart early Tuesday morning with the intention of arriving alongside Princes 4 in Hobart at 0900 Friday.
12/11/18	56-05.0S 153-27.9E	NW 34-40 kt	NW 16-18 ft	CTD 76 and CTD 77 were successfully completed. Conditions were suitable for a short Triaxus tow so the sled was deployed at 1858. Conditions were forecast to deteriorate as the night went on and by 2200 sea and swell was building sufficiently to call for a recovery. Triaxus was back on deck by 2242 and after it was secured we got underway for the start of a swath bathymetry survey line. The survey was started at 0005 and was continuing through noon today. Rough seas overnight and this morning have brought our speed over ground to around 6 kts and the hoped-for window for a final Triaxus tow is looking elusive. We'll likely continue the swath survey line across some bottom features that we completed on the southbound legs before heading north to Hobart later tonight. We'll do another swath survey line going north to parallel the southward track to add one smaller bit of

				bathymetric information to our charts of the Southern Ocean.
13/11/18	52-57.1S 150-22.3E	N 22-27 kt	N 10-12 ft	Sea and wind conditions remained persistently rough and the final Triaxus tow did not eventuate. We finished the final portion of the survey leg about 0130 this morning and then turned north for the return to Hobart. We're now running a final swath survey line parallel to the southward track taken at the start of V05 for the remainder of the voyage before arriving at Hobart on Friday. Weather remains less than perfect but it should ease somewhat as we get further north. All else is well on board and by all accounts so far it's been a successful cruise.
14/11/18	49-18.4S 149-25.9E	W 17-21 kt	W 6-8 ft	Ship is continuing underway to Hobart and conducting a swath survey line enroute. Weather is gradually improving albeit with enough of a ground swell to keep the ship in a lively mood. All else is well on board and crew and passengers are all looking forward to arrival in Hobart.
15/11/18	45-01.4S 148-50.7E	SSW 17-21 kt	SSW 5-7 ft	Ship is rolling deeply in a moderate following ground swell on an otherwise fine day. Skies are clear and the ship is receiving a long overdue fresh water wash while we continue swath mapping on the final leg—139nm to go at the time of this report. All else is well on board and there should be no delays in arrival alongside Princes 4 wharf, Hobart.
16/11/18	Return to Hobart			

Appendix C – Mooring Report (Mark Rosenberg and Jamie Derrick)

INVESTIGATOR CRUISE IN2018_V05 (IN1805, 16/11/2018 TO 16/11/2018) ACC-MEANDER MOORING DEPLOYMENT

Mark Rosenberg (ACE CRC) and Jamie Derrick (CSIRO CMAR)

October 2018

picture by Sarah Lanier

This report summarises information for the AAC-MEANDER mooring deployment. A final mooring diagram and deployment trackplot are included.

No previous cruises had been in the project area around the ACC meander, so no ship bathymetry was available, A potential mooring target at 55^o 46.2'S 151^o 00.0'E was picked prior to the cruise from ETOPO and Smith-Sandwell bathymetries, the aim being to find an area suitably flat and within the meander. The ship reached the target in the evening of day 4 of the cruise, and a swath bathymetry survey was done. The bottom was too rough around the original target, but a suitable target was identified at 55^o 32.67'S 150^o 51.42'E, ~14 miles to the north of the original and still within the meander. This was a lucky break, as the bottom was typically very rough with flat spots hard to come by. The shallowest instrument was targeted for 100 m below the surface, so a suitably flat and sufficiently large target were essential. A CTD was done at the new target site, to confirm the depth and to provide a sound speed profile for the swath array.

A weather window was predicted for the next day (day 5 of the cruise), though this window was tight as the forecast indicated stronger winds and swell in the early afternoon. Deployment commenced at ~0630 local time, and the whole operation went smoothly, with no significant problems. Total time from deployment of the surface beacon to anchor release was just under 7 hours, with wind and swell conditions remaining good throughout. Deployment commenced ~10 miles south of the target, and the ship maintained it's course, passing right over the target at the end. The anchor was released ~0.5 miles north of the target.

The mooring line lengths included a 400, 200, 100 and 50 m shot of dynex just before the lowest fixed dynex length of 140 m, all pre-spooled onto the winch. This allowed flexibility in total mooring length of 3200 to 3950 m in 50 metre increments. During the deployment, everything was stoppered off when these extra shots were reached, and 350 m of line (i.e. 200, 100 and 50) were spooled off the winch drum, based on the predicted depth at the anticipated anchor landing site i.e. targeting the top of the mooring at ~130 m below the surface.

Final deployment data from triangulation of acoustic releases

Triangulated landing site: **55^o 32.544'S , 150^o 52.332'E**
Bottom depth: **3620 m**
Depth of top of mooring: **120 m**
Anchor release time: **0223 on 20/10/2018 UTC**
Sound speed for triangulation: **1484.5 m/s (from CTD)**
Anchor dragback: **1213 m towards 127^o**

GENERAL PREPARATION AND DEPLOYMENT NOTES

* The CSIRO winch was used, and all line (except for the final tether/wire/parachute) was spooled on in port (wire on one half, dynex on the other).

* A couple of 2 ton strops were used as a stopper, from the little tugger at the base of the winch.

* Microcats, Aquadopps and releases were stored in the CSIRO mooring container at the forward end of the deck. Glass floats were stored in a half height on the starboard side. The ADCP's were lashed down next to the halfheight. The anchor stacks were lashed to the deck just forward of the port ramp space wall. During the deployment, ADCP's and anchors were moved into deployment positions with a pallet jack.

* ADCP operation was confirmed prior to sailing, after loading them on the ship. Testing of acoustic releases and confirmation of Aquadopp operation were both done on day 2 of the cruise

* Line was paid out along the deck, running though the CSIRO yellow mooring fairlead at the stern (just starboard of centre). Mooring components were deployed by the A-frame, lifting with the 2 hoists (union join) via a quick release. The following quick releases were used: TR5 for the ADCP's, WHOI release for glass floats/aquadopps/releases, and TR8 for the anchor.

* As each premarked microcat position was reached, paying out was stopped while the microcat was fitted (near the winch). After fitting, the microcat was walked down the deck and manually guided through the yellow fairlead at the stern.

* During extended periods of stoppering, the line passing over the yellow fairlead can chaff. Chaff protectors around the dynex terminations prevented this problem. For the wire, on one occasion a piece of layflat was used to ease chaffing.

* The pair of acoustic releases had been assembled with the open end of the release hooks facing inward, opposite to the usual arrangement. It didn't seem to be a problem, as both hooks were able to swing open for release.

* When the releases were reached, the 10 mm wire (with the parachute inline) and the 15 m nylon tether were backspooled onto the winch. The releases and final float group were then deployed.

* The anchor (triple stack of railway wheels) was positioned and rigged for deployment on the final run to the target. Tag lines were used from either side of the ramp space. By the time everything was rigged it was time to deploy (~0.5 miles past the target). With the anchor and parachute both in the water, the 'chute was released and allowed to commence opening, then the anchor was released.

* Deployment of components was noted to the elog in Ops (giving a time and position stamp). In water times were also noted down on the deck (in the container).

picture by Sarah Lanier

picture by Sarah Lanier

ACC-MEANDER MOORING DEPLOYMENT

* targetting depth of 3630 m. Figure 1 is the mooring diagram; Figure 2 is the deployment trackplot.

Mooring component	UTC time in the watewr
surface beacon, microcat-9334	1930, 19/10/2018
8 glass floats	1933, 19/10/2018
microcat-9173	1943, 19/10/2018
microcat-9174	1949, 19/10/2018
ADCP-16413	2008, 19/10/2018
microcat-9175	2015, 19/10/2018
microcat-9176	2020, 19/10/2018
8 glass floats	2032, 19/10/2018
microcat-9177	2039, 19/10/2018
microcat-9182	2045, 19/10/2018
microcat-11402	2050, 19/10/2018
microcat-11403	2056, 19/10/2018
microcat-14035	2101, 19/10/2018
microcat-15021	2105, 19/10/2018
ADCP-3758, ADCP-14489	2132, 19/10/2018
microcat-15022	2203, 19/10/2018
microcat-13080	2207, 19/10/2018
6 glass floats	2219, 19/10/2018
microcat-13083	2234, 19/10/2018
microcat-13084	2230, 19/10/2018
microcat-13087	2236, 19/10/2018
microcat-13263	2243, 19/10/2018
aquadopp-1401, microcat-13265, 6 glass floats	2259, 19/10/2018
aquadopp-1414, microcat-13266, 6 glass floats	2329, 19/10/2018
stoppered off to spool off 200, 100 and 50 m dynex shots	~0000, 20/10/2018
aquadopp-1484, microcat-13267	0025, 20/10/2018
aquadopp-1502, microcat-13268, 6 glass floats	0127, 20/10/2018
releases 22769 and 24587	0131, 20/10/2018
anchor	0223, 20/10/2018

At anchor release:

position = 55° 32.15' S,150° 51.40'E
depth = 3657 m

3

MOORING TRIANGULATION

Triangulation of the mooring releases began ~1 hour after anchor release – ample time for the anchor to land on the bottom. All communication was loud and clear, using release 22769 only.
Final calculations from triangulation program:

triangulated landing site: 55° 32.544'S , 150° 52.332'E
releases at 3558 m, anchor depth 3619 m
(using sound speed 1484.5 m/s, and releases 55 m above bottom)

The ship then ran right over the calculated landing site, and ranges were checked again:

minimum slant range = 3554 m

Depth over the landing site from the swath was 3621 m, in close agreement with the 3619 m value from the triangulation. **Taking the average of these, a final bottom depth of 3620 m is assumed, putting the top of the mooring at 120 m below the surface.** Figure 3 shows the triangulation.

ACKNOWLEDGMENTS

Many thanks to the ship's crew for all the deck work and navigation. Big thanks to Brett Muir for instrument handling on the deck, to Don Mckenzie for safety oversight throughout the deployment, and to MNF/CSIRO technical staff.

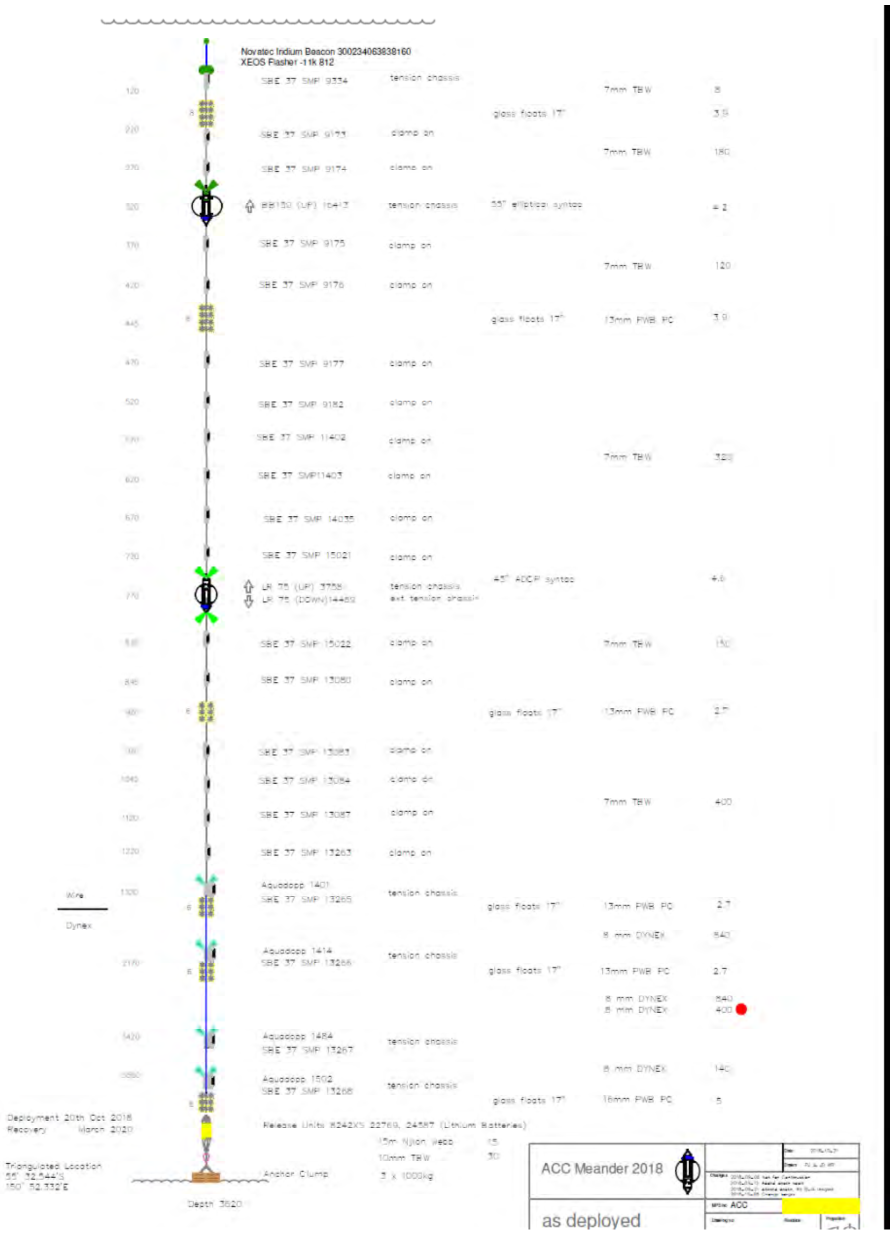


Figure 1: Mooring diagram, as deployed.

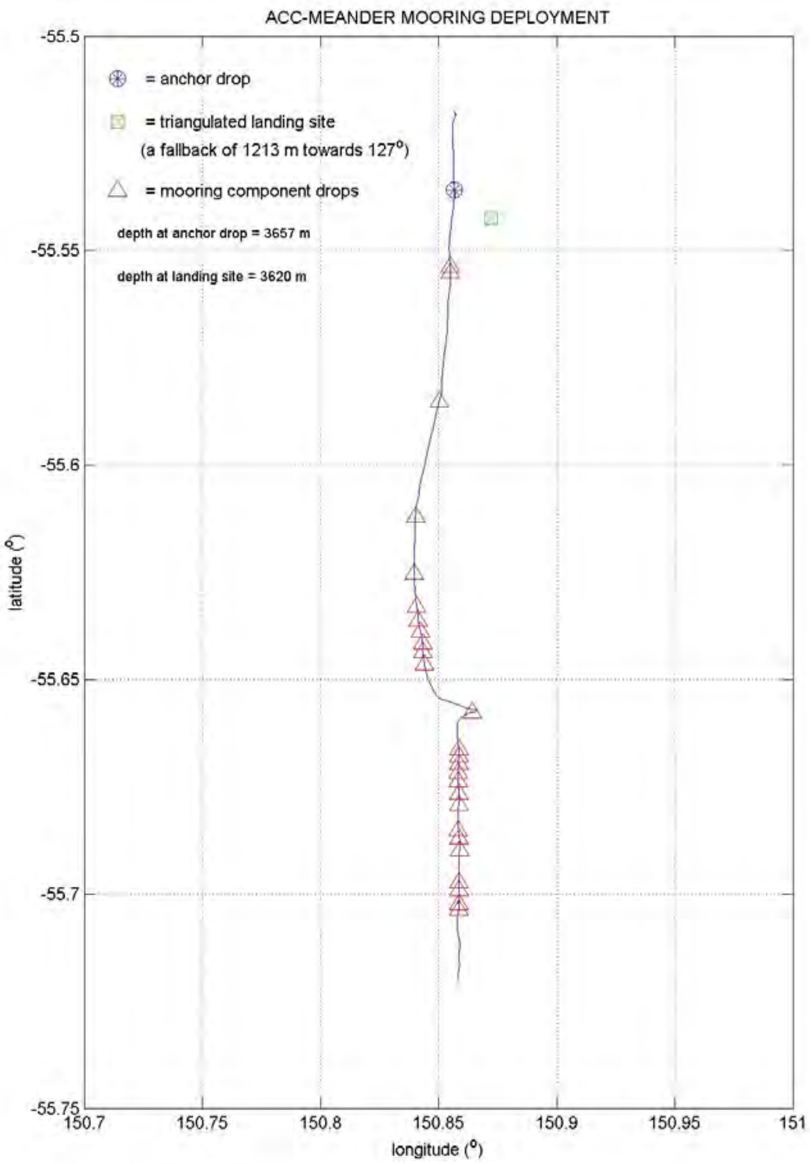
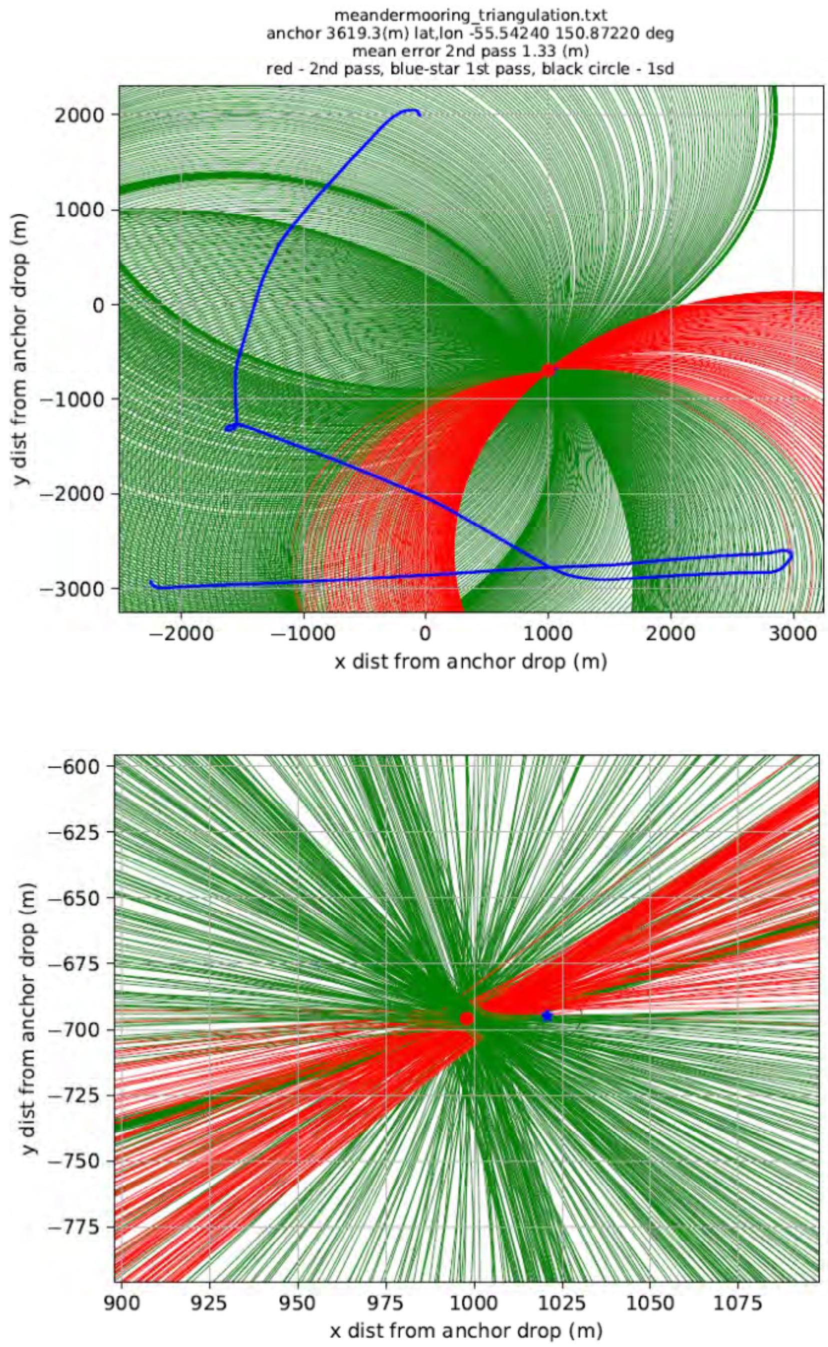


Figure 2: Mooring deployment trackplot, including ship's track.



<u>Figure 3:</u> Mooring triangulation result (second graph is a zoom in).

Appendix D – VMP Report (Kurt Polzin, WHOI)

1 VMP-2000 (Preliminary Report)

This section reports on the use of a Rockland Scientific International (RSI) Vertical Microstructure Profiler (VMP-2000) during the R/V Investigator cruise IN2018_V05. The VMP has 2 shear probes for estimating millimeter scale velocity gradients, 2 fast response FP07 thermistors to estimate centimeter scale temperature gradients and a dual needle conductivity probe of higher effective resolution than that of the temperature sensors. The goal of these sensors is to provide gradient variance estimates on the scales at which molecular viscosity and thermal diffusivity are dynamically important. The primary use of the conductivity sensor is to define the dynamic time response of individual thermistors via an in situ calibration. Interpreted in the context of production - dissipation balances, these variance estimates can be related to turbulent dissipation rates, turbulent production and buoyancy flux estimates. These balances are assumption dependent, relying upon isotropic relations that obtain at high Reynolds number. The goal of the processing described below is to provide the 'best' possible estimate of the gradient variance, in which 'best' does not rely upon assumptions of the underlying dynamics. The VMP also has a pumped SeaBird conductivity and temperature sensor system and a Kellor strain gauge for pressure estimates. The CTD temperature and conductivity are used for in situ calibrations of the microstructure sensors and time rate of change of the pressure provides a fall rate estimate for use with the microstructure response.

The VMP was newly converted to internally recording operations from real time reporting with data relayed to shipboard using a conducting cable. This proved to be far easier to use. However, there are limitations. The VMP is a loosely tethered instrument designed to be operated in free-fall. The instrument was deployed eight times (casts 3-10) using a thicker and slightly positively buoyant line (dyneema) on the ship's light sediment coring winch. This resulted in additional noise which was not wholly mitigated by alternative data processing schemes.

Finally, operations were terminated when the VMP-2000 was lost during the 48^{th} deployment. The VMP was being deployed amidships while the bridge juggled currents and windage with the two propellors to keep the tether streaming away from the vessel. The tether drifted rapidly aft mid-cast, went under the stern and appeared to be cut cleanly. Hindsight suggests the option of streaming the instrument off the stern, but the stern quarters are occupied by permanent equipment and the area under the A-frame was utilized for both mooring and Triaxis deployments.

1.1 Operations

Forty eight deployments were undertaken with the VMP. Some of these contained multiple casts so that a total of 54 profiles to depths exceeding 1000 m were obtained. Cast and profile particulars can be found in Table 1.

A power convertor was integrated into the VMP hydraulics package prior to shipping to deal with the conversion of Australian 415V 50 Hz to US 480V 60 Hz standards. The power convertor was not set up properly so the convertor's circuit breaker kept tripping. The VMP was switched over to the light sediment winch for profiles 3-10. This winch had a thicker line with slight positive buoyancy that required greater effort to 'pull'. Increased coupling with the surface wave field and slower fall rates were observed. The end result was variable fall rates, increased tension and greater vibrational noise in the shear sensors. Software modifications are described in the microstructure subsection below. The VMP winch was utilized post cast 10 after obtaining the complete 17 step instruction set for the power convertor from the manufacturer.

Table 1: Station Particulars: time, space and name. The RSI binary files (DAT_xxx.P) were converted to MatLab format using odas_P2mat and then renamed from the numerical convention on the flash drive in the instrument to a scheme corresponding to cast number (VMP_yyy.mat), column 6.

event	date	time in / out	latitude	longitude	file naming
		(UTC)	(in)	(in)	- comments -
VMP 001 / no CTD	17 / 10 / 2018	21:42 / 22:53	-49.8396	149.3595	DAT_025 → VMP_001
					test station
VMP 002 / CTD 02	20 / 10 / 2018	06:15 / 07:54	-55.5606	150.7957	DAT_027 → VMP_002
VMP2a		06:15	-55.5606	150.7957	surface - 324 dBar
VMP2b		06:31	-55.5607	150.7961	surface - 1539 dBar
					change to sediment winch
VMP 003 / CTD 08	21 / 10 / 2018	23:57 / 01:35	-54.8857	149.1944	DAT_032 → VMP_003
VMP 004 / CTD 09	22 / 10 / 2018	12:46 / 14:04	-55.6109	149.9768	DAT_034 → VMP_004
VMP 005 / CTD 10	22 / 10 / 2018	22:39 / 23:57	-55.4783	150.0595	DAT_035 → VMP_005
VMP 006 / CTD 12	23 / 10 / 2018	09:45 / *	-55.2061	150.0158	DAT_036 → VMP_006
					*low battery condition
VMP 007 / CTD 13	23 / 10 / 2018	16:04 / *	-55.1099	150.1050	DAT_037 → VMP_007
					*low battery condition
VMP 008 / CTD 15	24 / 10 / 2018	13:07 / 14:38	-55.6581	150.7660	DAT_038 → VMP_008
VMP 009 / CTD 16	24 / 10 / 2018	19:37 / 21:08	-55.5340	150.6778	DAT_041 → VMP_009
VMP 010 / CTD 17	25 / 10 / 2018	02:17 / 03:36	-55.4064	150.7597	DAT_042 → VMP_010
					change to VMP winch
VMP 011 / CTD 20	25 / 10 / 2018	22:05 / 23:39	-54.9947	150.7712	DAT_044 → VMP_011
VMP 012 / CTD 21	26 / 10 / 2018	06:19 / 07:19	-54.8656	150.7427	DAT_046 → VMP_012
VMP 013 / CTD 22	26 / 10 / 2018	23:31 / 00:40	-55.7921	152.1465	DAT_047 → VMP_013
VMP 014 / CTD 23	27 / 10 / 2018	06:05 / 07:20	-55.6636	152.0942	DAT_048 → VMP_014
VMP 015 / CTD 24	27 / 10 / 2018	11:56 / 13:04	-55.5058	152.0247	DAT_050 → VMP_015
VMP 016 / CTD 25	27 / 10 / 2018	17:49 / 19:03	-55.4009	151.9636	DAT_054 → VMP_016
VMP 017 / CTD 26	27 / 10 / 2018	23:05 / 00:15	-55.2510	151.9104	DAT_057 → VMP_017
VMP 018 / CTD 27	28 / 10 / 2018	04:53 / 06:05	-55.1278	151.8748	DAT_058 → VMP_018
VMP 019 / CTD 31	29 / 10 / 2018	01:03 / 02:19	-54.5775	151.7829	DAT_060 → VMP_019
VMP 020 / CTD 32	29 / 10 / 2018	07:05 / 08:11	-54.4326	151.7686	DAT_067 → VMP_020
VMP 021 / CTD 34	30 / 10 / 2018	11:35 / 12:40	-55.4831	153.3476	DAT_068 → VMP_021
VMP 022 / CTD 35	30 / 10 / 2018	17:16 / 18:30	-55.5733	153.1746	DAT_069 → VMP_022
VMP 023 / CTD 36	30 / 10 / 2018	23:31 / 00:39	-55.6523	153.0214	DAT_070 → VMP_023
VMP 024 / CTD 40	31 / 10 / 2018	19:50 / 20:55	-55.9670	152.2655	DAT_072 → VMP_024
VMP 025 / CTD 40	31 / 10 / 2018	21:27 / 23:45	-55.9724	152.2923	DAT_073 → VMP_025
VMP 25a		21:27 / 22:35	-55.9724	152.2923	
VMP 25b		22:35 / 23:45	-55.9821	152.3131	
VMP 026 / CTD 41	01 / 11 / 2018	08:58 / 10:06	-56.4024	153.1024	DAT_074 → VMP_026
VMP 027 / CTD 42	01 / 11 / 2018	14:18 / 15:30	-56.3045	153.2125	DAT_075 → VMP_027
VMP 028 / CTD 43	01 / 11 / 2018	19:44 / 20:53	-56.2091	153.3322	DAT_076 → VMP_028
VMP 029 / CTD 44	02 / 11 / 2018	01:15 / 02:19	-56.0648	153.3987	DAT_079 → VMP_029
VMP 030 / CTD 45	02 / 11 / 2018	06:42 / 07:49	-55.9630	153.6369	DAT_080 → VMP_030

see next page

Station Particulars, continued

event	date	time in / out (UTC)	latitude (in)	longitude (in)	file naming comments
VMP 031 / CTD 46	02 / 11 / 2018	15:52 / 16:40	-55.7811	153.7283	DAT_081 → VMP_031
VMP 032 / CTD 47	02 / 11 / 2018	21:57 / 23:03	-55.6381	153.8927	DAT_082 → VMP_032
VMP 033 / CTD 48	03 / 11 / 2018	09:52 / 10:59	-56.5683	153.9616	DAT_086 → VMP_033
VMP 034 / CTD 51	04 / 11 / 2018	03:45 / 04:51	-56.1819	154.3328	DAT_087 → VMP_034
VMP 035 / CTD 52	04 / 11 / 2018	08:30 / 09:45	-56.0838	154.4809	DAT_088 → VMP_035
VMP 036 / CTD 56	05/ 11 / 2018	05:30 / 08:40	-55.6318	154.9255	DAT_089 → VMP_036
VMP 036a		05:30 / 06:35	-55.6318	154.9255	
VMP 036b		06:35 / 07:35	-55.6389	154.9260	
VMP 036c		07:35 / 08:40	-55.6456	154.9262	
VMP 037 / CTD 57	05 / 11 / 2018	20:55 / 23:11	-56.8531	155.1879	DAT_091 → VMP_037
VMP 037a		20:55 / 21:59	-56.8531	155.1879	
VMP 037b		21:59 / 23:11	-56.8601	155.1967	
VMP 038 / CTD 58	06 / 11 / 2018	06:45 / 07:57	-56.7327	155.1908	DAT_092 → VMP_038
VMP 039 / CTD 59	06 / 11 / 2018	12:27 / 13:30	-56.5980	155.2421	DAT_093 → VMP_039
VMP 040 / CTD 60	06 / 11 / 2018	17:44 / 18:48	-56.4731	155.2669	DAT_094 → VMP_040
VMP 041 / CTD 61	06 / 11 / 2018	23:44 / 00:50	-56.3672	155.3740	DAT_095 → VMP_041
VMP 042 / CTD 62	07 / 11 / 2018	06:12 / 07:16	-56.2348	155.4118	DAT_096 → VMP_042
VMP 043 / CTD 63	08 / 11 / 2018	10:22 / 01:39	-56.0699	156.1154	DAT_099 → VMP_043
VMP 043a		10:22 / 11:25	-56.0699	156.1154	
VMP 043b		11:25 / 12:28	-56.0814	156.1543	
VMP 043c		12:28 / 13:39			
VMP 044 / Triaxis	08 / 11 / 2018	22:06 / 23:17	-56.8633	156.1555	DAT_100 → VMP_044
VMP 045 / Triaxis	08 / 11 / 2018	23:44 / 01:51	-56.9013	156.1855	DAT_101 → VMP_045
VMP 045a		23:44 / 00:51	-56.9013	156.1855	
VMP 045b		00:51 / 01:51	-56.9249	156.1918	
VMP 046 / CTD 68	09 / 11 / 2018	11:56 / 13:03	-57.2732	156.0921	DAT_102 → VMP_046
VMP 047 / CTD 69	09 / 11 / 2018	17:17 / 18:25	-57.1337	156.1048	DAT_103 → VMP_047

1.2 Finestructure

CTD performance

The VMP utilizes a pumped SeaBird (SBE) 3-4 T/C sensor system and Keller pressure transducer. The SBE sensor output is routed through the RSI electronics and combined with data from the pressure sensor. The response of the SBE T and C sensors is a function of the pump rate, the time constant of the thermometer, the physical distance between the T and C sensors, and the length and thermal inertia of the C sensor (Lueck and Picklo, 1990[1]; Morrison et al., 1994[2]; Johnson et al., 2007[3]). Following Johnson et al. (2007), a time offset of 2 scans (0.0302 seconds at 64 Hz) for fluid parcels to travel from the temperature sensor to the conductivity sensor was deduced, and a

[1] Lueck, R.G., and J.J. Picklo, 1990. Thermal inertia of conductivity cells: Observations with a Sea-Bird cell. J. Atmos. Oceanic Technol., 7, 754-768.

[2] Morrison, J., R. Andersen, N. Larson, E. D'Asaro and T. Boyd, 1994. The correction for thermal-lag effects in Sea-Bird CTD data. J. Atmos. Oceanic Technol., 11, 1151-1164.

[3] Johnson, G. C., J. M. Toole, and N. G. Larson, 2007. Sensor corrections for Sea-Bird SBE-41CP and SBE-41 CTDs. Journal of Atmospheric and Oceanic Technology, 24, 1117-1130.

thermal mass time constant for the conductivity cell was estimated. The temperature of the sea water in the conductivity cell may be predicted with the following (in Matlab):

```
[b,a]= butter(1,thermal_mass_time_constant);
Tcell = filter(b,a,Tsbe);
```

with a thermal_mass_time_constant of 0.2.

In words, the cell temperature is predicted from a recursive single pole Butterworth filter applied to the measured temperature. Salinity is then derived using the measured conductivity and the filtered temperature data.

The SBE unit was missing its small plastic T/C duct and this likely limits further enhancements of salinity quality through data processing.

Table 2: Calibrations for the SBE 3 and 4 T and C modules and pressure transducer used during X-Stream TV. The SBE are manufacturer's cals supplied when the units were purchased and are part of the hardware. The RSI configuration file SETUP.TXT implements the manufacture's calibration as per Rockland's literature.

sensor	serial number	calibration date
SBE 03F.320	03-6225	08-Apr-2017
SBE 04C.320	04-4691	30-Mar-2017
SBE 05T.22221	05-9135	
Keller PA11/80059/600Bar	143543	02-Aug-2018

1.3 Microstructure

The VMP's microstructure suite consists of two air foil shear probes, two FP07 fast response thermistors and a dual needle conductivity probe. Shear probe data are subject to contamination by mechanical vibrations induced by vortex shedding from the instrument and that communicated through the tether if it is under significant tension. The micro-temperature data are generally high quality and calibrated in situ against the VMP's CTD. Pre-emphasized micro-conductivity data suffers from high noise levels. Cleaning / pre-wetting with a 1% Triton-X solution per manufacturer's suggestion improved conductivity sensor performance. Probe usage and calibration information is contained in Tables 3-6.

Table 3: Shear probe usage and assessments.

cast	Sx	Sy	notes
01-11	M1603	M1604	M1604 removed for being 'sketchy'
12-14	M1603	M1606	however, M1606 is 2x ϵ from M1603
15	M1548	M1606	and 2x ϵ from M1548
16	M1548	M1553	so we replace M1606 with M1553. M1553 is 2x M1548
17-23	M1553	M1548	so we swap S1 and S2
24-28	M1597	M1599	with bias issue unresolved, we replace both probes
29-32	M1553	M1599	M1597 has a case of the fuzzies.
33-36	M1599	M1553	M1553 has a case of the fuzzies. Swap probes to diagnose.
37-48	M1597	M1553	M1599 'sketchy'. Replaced probe. Noise likely moisture related.

Table 4: Shear probe sensitivities and calibration dates

M1603	0.0782	Jan. 04, 2017
M1604	0.0780	Jan. 04, 2017
M1606	0.0664	Jan. 04, 2017
M1548	0.0837	Oct. 19, 2016
M1553	0.0623	Oct. 18, 2016
M1597	0.0656	Jan. 03, 2017
M1599	0.0685	Jan. 03, 2017

Table 5: Temperature probe usage and assessments.

cast	T1	T2	notes
01 - 43	# 1356	# 1400	µT2 died
44 - 45	# 1356	# 1405	poor response on µT2
46 - 47	# 1356	# 1401	µT2 died
48	# 1356	# 1402	

The data were processed using the program micro_diagnostics_v1.9 which has extensive diagnostic tools. Data processing occurs in two major steps. A first pass is used to document the basic character of the noise, which then informs refinements to the algorithm concerning integration limits and avoiding vibrational peaks in the shear data. The processing algorithms were adapted from those described in Polzin and Montgomery (1996)[4].

- Data were despiked using RSI's despike algorithm: e.g. despike(sh1(M1:M2), 7, 1, 512, 20).
- Data were transformed in three half-overlapping segments of 1 second length windows.
- Preliminary estimates of ϵ and χ were made and bin averaged in logarithmic intervals, Figure 3. This process reveals noise of both vibrational and electronic origin, and these then suggest ways to structure integration endpoints to maximize signal-to-noise ratios.

The rate of dissipation of turbulent kinetic energy ϵ is estimated from formulas assuming isotropic relations between components of the rate of strain tensor as $\epsilon = \frac{15}{2}\nu S = \frac{15}{2} \times 1.5 \times 10^{-6}$ $m^2 s^{-1} P_n(f) \times 10$ cps with molecular viscosity ν and S representing either the shear variance of a single probe or the average of two. Integrating over 10 cps, the quoted noise spectra translate into dissipation rates of 1.25×10^{-11} W/kg. These are not average electronic noise levels. A Gaussian white process, which plausibly describes the electronic noise in the shear sensor, has an average variance whose statistical uncertainty decreases with increasing number of independent estimates, N, of the variance. The quoted noise levels represent the those 1/2 Dbar data segments having the lowest 5-10% of the sample variances, with the complication that the sample data have contributions from both noise and oceanic signal. These shear noise estimates are very much lower bounds on the average noise. Also note that the quoted values represent what a 'healthy' instrument is

[4]Polzin, K. L. and E. T. Montgomery, 1996: Deep microstructure profiling with the High Resolution Profiler. Proceedings of the Microstructure Sensors Workshop, 23-25 October 1996, Timberline Lodge, Mt. Hood, Oregon, USA.

Table 6: Conductivity probe usage and assessments.

cast	C1	notes
01 - 16	# C221	
17 - 45	# C237	newer probe / lower sensitivity
46 - 48	# C239	used Triton-X. much improved.

capable of. In contrast, the curve fits for temperature and conductivity noise represent the average electronic noise spectra of the system.

Analytic representations of the noise spectra (P_n) are
shear probes: $P_n(f) = A\ 1.0 \times 10^{-7}\ s^{-2}/\ cps$
temperature: $P_n(f) = B\ 0.12 \times 10^{-10} \times f^{3.25}\ [sinc(f/512)]^4\ C^2 m^{-2}\ /\ cps$
conductivity: $P_n(f) = C\ 1.25 \times 10^{-8} \times f^{2.0}\ [sinc(f/512)]^4\ mmho^2 m^{-2}\ /\ cps$

with f being frequency in cycles per second (cps), $sinc(x) = \sin(\pi x)/\pi x$ and 512 Hz being the sampling rate of the microstructure data. Anti-aliasing filters with transfer function $[1.0 + (f/98)^8]^2$ are additionally applied to the data but are not included at this step.

Refinements to the basic algorithm were three fold.

1. The factors [A B C] vary slowly with fall rate W and may also vary from dive to dive. Hitherto this variability has not been sufficient to warrant using anything other than [A B C] = [1 1 1]. This approach did not work well when using the ship's winch and thus speed dependent noise spectra were introduced: $[A\ B\ C] = [1\ 1\ 1] \times (\frac{0.7}{W})^2$. All casts were processed with this upgrade.

2. The upgrade revealed further efforts were required for profiles 3-10. Understanding that increased tether tension was likely when using the ship's winch suggested employing the RSI routine that subtracts signals coherent with accelerometers in the nose of the instrument. Significantly better agreement with the Nasmyth curves were obtained when using one second piece lengths averaged over 11 seconds. Transform piece lengths of 2 seconds could be investigated. A separate processing code file was named: micro_diagnostics_v1.9w.

3. The VMP appeared to spear a piece of biology during cast 43a that remained during subsequent down casts 43b and 43c. Here integration of the shear-1 data excluded a vibrational peak at 7 and 8 Hz and data from shear-2 should be discarded. The processing code is named micro_diagnostics_v1.9.43.

The end point of this process is a set of files named: MicroRepro_xxx.y_z.mat with 'xxx' = deployment number with alphabetic extension representing a multiple cast, 'y' denoting use of fall rate dependent noise specifications (1='no' and 2 = 'yes'), 'z' = '.w' denoting winch profiles using the RSI noise subtraction routine (absent if otherwise). Final versions will have y=3. Variable names appear in Table 7.

After the initial processing, a mask is developed to discard noisy data. For a normal data set, this mask consists of two steps:

1. Turbulence has a correlation length scale, so individual variance estimates that stand out by more than an order of magnitude from their neighbors are invariably noisy. Such incidences are rendered as NaNs.

Table 7: Variable assignments in MicroRepro.xxx.y.z.mat files.

variable name	type	units
bin_P	pressure	[dBar]
Tsb	in situ SeaBird temperature	[C]
Csb	SeaBird conductivity	[Siemens m^{-1}]
Ssb	SeaBird Salinity	[psu]
nscan	microstructure scan number of 1/2 dBar bin center	
Fallrate	descent rate derived from dP/dt	[m s^{-1}]
ϵ_1	TKE dissipation rate	[W kg^{-1}]
ϵ_2	TKE dissipation rate	[W kg^{-1}]
χ_1	thermal dissipation rate	[C^2 s^{-1}
χ_2	thermal dissipation rate	[C^2 s^{-1}
χ_c	conductivity derived thermal dissipation rate	[$Siemens^2$ m^{-2} s^{-1}]

2. With redundant estimates of the same variable, a scatter plot often suggests $\epsilon_i > a\epsilon_j$ is indicative of noise. Values of the parameter a are typically 3-6, figure 4. Extreme variance estimates are replaced by NaNs using this condition. The scatter plots also has the potential for revealing bias between two similar sensors, as in Figure 4. The cause of this bias was investigated by swapping probes and having the bias swap channels. This rules out electronic or software explanations. Bias between the shear data could result from mechanical changes within the probe or a pyrolytic tendency (temperature dependent calibration). This particular data set should not be considered 'final' until the shear probes can be recalibrated by the manufacturer.

• A preliminary attempt to define the mask is contained in the file readme.txt. This includes significant segments of casts 3-10 using the ship's winch that had large variations in fall rate and I could not work myself around to trusting them.

• In situ calibrations for the individual time constants were not attempted. The calculation requires regions of large density ratio (small contributions of salinity gradients to buoyancy) having dissipation in excess of 1×10^{-8} W/kg and high signal to noise ratios in the micro-conductivity. The data set has not been parsed for these criteria.

• The MicroRepro files produced on board need to be regarded as preliminary until the shear probes can be recalibrated by the manufacturer.

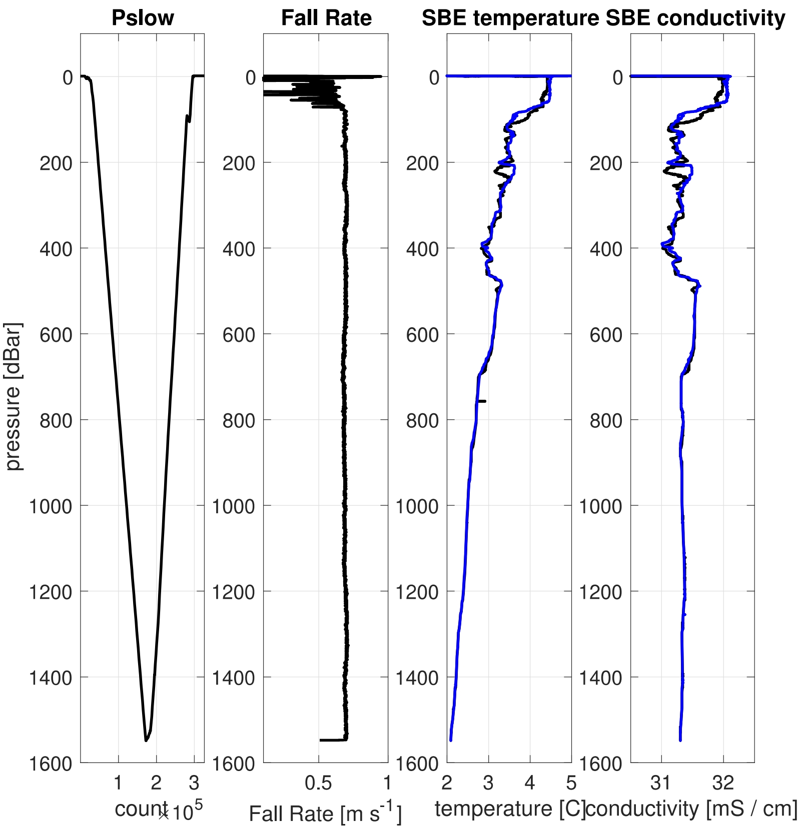
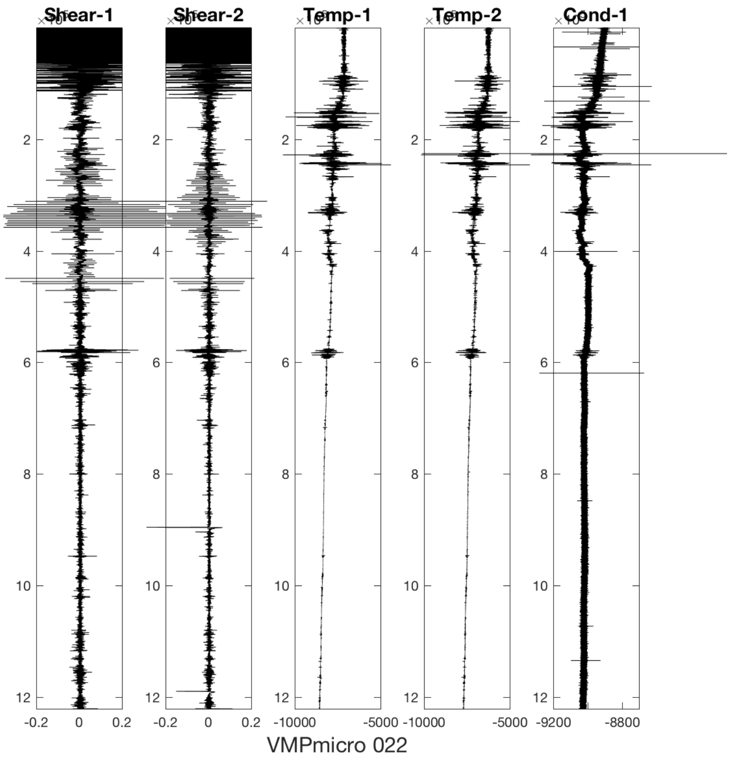
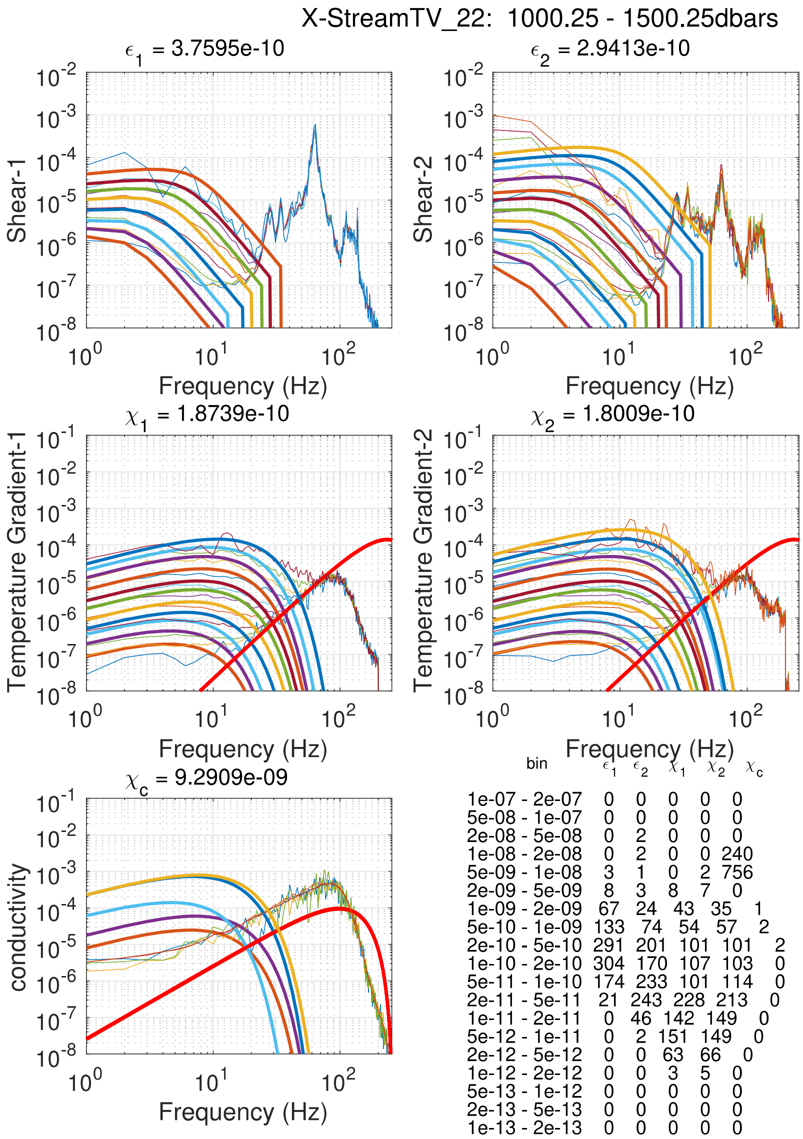


Figure 1: Cast 22 raw CTD data in vertical profile. Upward traces of temperature and conductivity are rendered in blue.



ata have been low-passed to about 10 Hz. Spikes from shipboard acoustics are evident in the shear data at scans less than 5×10^5.



bin	ϵ_1	ϵ_2	χ_1	χ_2	χ_c
1e-07 - 2e-07	0	0	0	0	0
5e-08 - 1e-07	0	0	0	0	0
2e-08 - 5e-08	0	2	0	0	0
1e-08 - 2e-08	0	2	0	0	240
5e-09 - 1e-08	3	1	0	2	756
2e-09 - 5e-09	8	3	8	7	0
1e-09 - 2e-09	67	24	43	35	1
5e-10 - 1e-09	133	74	54	57	2
2e-10 - 5e-10	291	201	101	101	2
1e-10 - 2e-10	304	170	107	103	0
5e-11 - 1e-10	174	233	101	114	0
2e-11 - 5e-11	21	243	228	213	0
1e-11 - 2e-11	0	46	142	149	0
5e-12 - 1e-11	0	2	151	149	0
2e-12 - 5e-12	0	0	63	66	0
1e-12 - 2e-12	0	0	3	5	0
5e-13 - 1e-12	0	0	0	0	0
2e-13 - 5e-13	0	0	0	0	0
1e-13 - 2e-13	0	0	0	0	0

Figure 3: Cast 22 microstructure spectra bin averaged in logarithmic intervals $[1-2, 2-5, 5-10...] \times 10^{-11}$, for shear-1 (upper left), shear-2 (upper right), temperature-1 (middle left), temperature-2 (middle right) and conductivity (lower left). The shear (temperature) spectra additionally have the Nasmyth (Batchelor) curves superimposed. Thick red lines in the temperature and conductivity spectra are the working estimates of electronic noise. Obvious data quality issues include: anomalous large shear-2 spectra and an underestimate of the conductivity noise in this sensor.

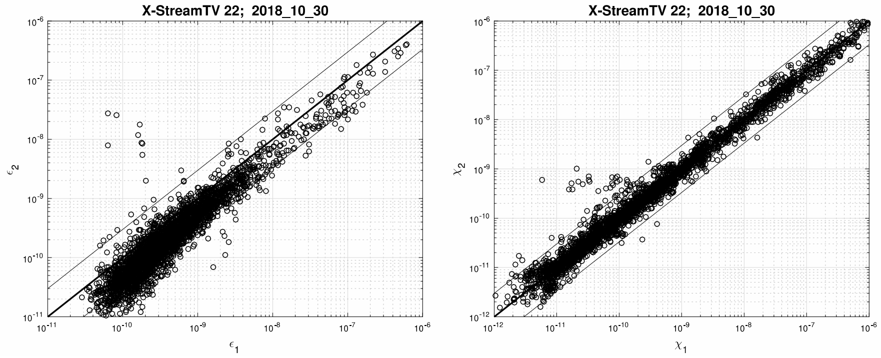


Figure 4: Cast 22 scatter plots of ϵ_1 vs. ϵ_2 (left) and χ_1 vs χ_2 (right). Thick straight lines represent $\epsilon_1 = \epsilon_2$ and thin lines demarkate $\epsilon_i = 3\epsilon_j$. A bias between ϵ_1 and ϵ_2 is apparent.

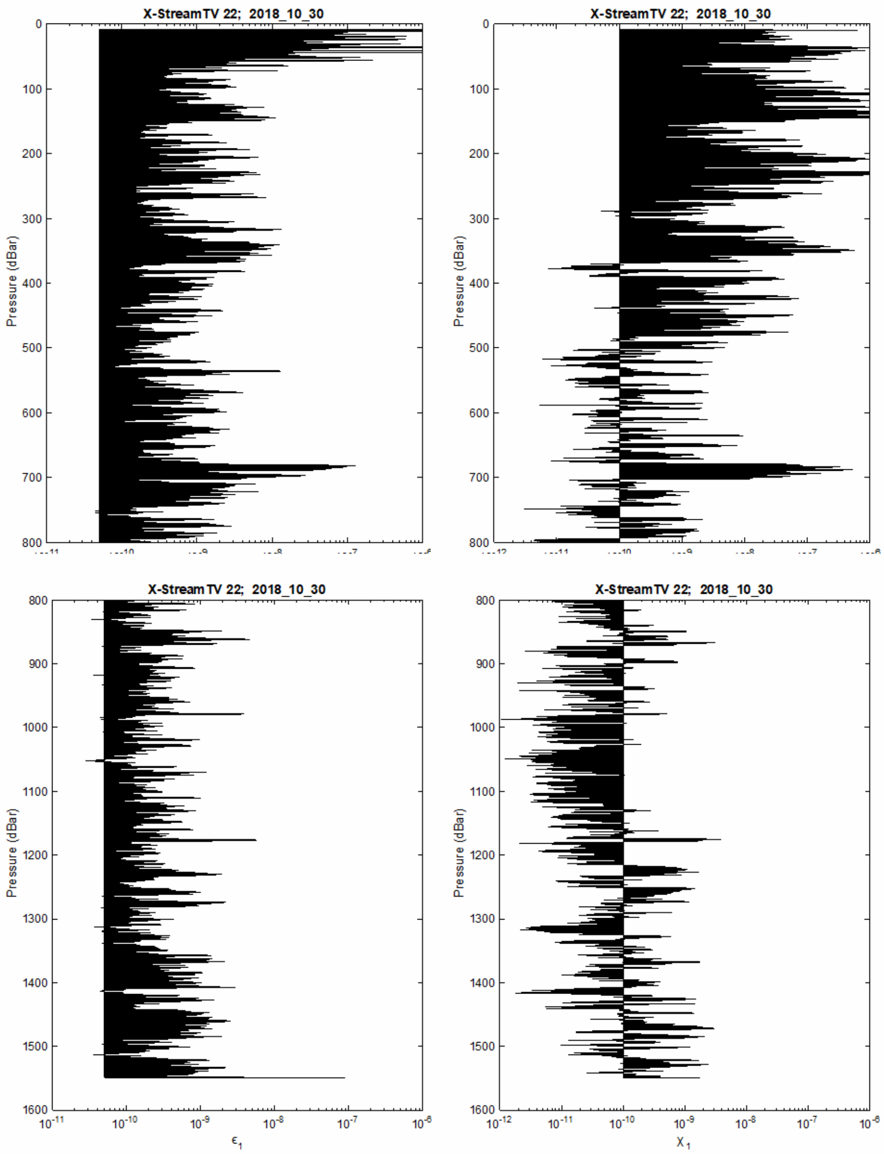


Figure 5: Cast 22 depth profiles of ϵ_1 (left) and χ_1 (right) from MicroRepro_022_2.mat.

Appendix E – Photographs

Credit: Annalise Rees