RV *Investigator* Voyage Plan

Version 4 7 September 2018

Voyage #:	IN2018_V05		
Voyage title:	How does a standing meander southeast of Tasmania brake the Antarctic Circumpolar Current?		
Mobilisation:	Hobart, Tuesday, 16th October 2018		
Depart:	Hobart, Tuesday, 16th October 2018, targeting 16:00.		
Return:	Hobart, Friday, 16th November 2018, targeting 10:00.		
Demobilisation:	Hobart, Friday, 16th November 2018		
Voyage Manager:	Don McKenzie	Contact:	0419 534 771
Chief Scientist:	Prof Nathan Bindoff		
Affiliation:	IMAS, University of Tasmania	Contact:	n.bindoff@utas.edu.au 0417 011 090
Principal Investigator:	Dr Steve Rintoul		
Affiliation:	CSIRO Oceans and Atmosphere	Contact:	steve.rintoul@csiro.au
Principal Investigator:	Dr Helen Phillips		
Affiliation:	IMAS, University of Tasmania	Contact:	h.e.phillips@utas.edu.au 0439 851 249
Principal Investigator:	Dr Max Nikurashin		
Affiliation:	IMAS, University of Tasmania	Contact:	Maxim.nikurashin@utas.edu.au
Principal Investigator:	Dr Kurt Polzin		
Affiliation:	Woods Hole Oceanographic Institution, USA	Contact:	kpolzin@whoi.edu
Piggy-back Project name:	Upper ocean biogeochemistry in the Macquarie Meander of the Antarctic Circumpolar Current		
Principal Investigator	Dr Peter Strutton		
Affiliation:	IMAS, University of Tasmania	Contact:	peter.strutton@utas.edu.au 0488 304 012

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 global warming, 65% of which is taken up in the Southern Ocean, 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 back upon the global circulation and 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.

<u>*Objectives*</u>

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.

Lost time will be dealt with through paring down time spent on objectives 3-4.

Operational Risk Management

Over the side operations include deployment of the CTDs, profiling floats, drifters and TRIAXUS. All of these activities have been performed on Investigator before and standard safety protocols will be followed.

Mooring operations will follow the usual stern A-frame deployment methods used, for example, during the SOTS mooring voyages of Tom Trull. Deployment will follow the approved procedures and ASP to update JHAs on board to suit the proposed mooring. A diagram of the mooring is provided at the end of this document.

Overall activity plan including details for first 24 hours of voyage

Assuming that the weather is favourable, the workflow in order of activity is

1) Transit from Hobart to test station off the continental shelf in 3000 m of water depth. We will test CTD, LADCP and VMP operations. Triaxus can be tested if required.
2) Transit from test station to the mooring location near 56° 10.6'S; 151° 17.10'E and complete mooring deployment.
3) Transit to western leg of CTD survey. Begin CTD/LADCP/VMP stations. Deploy floats and drifters along the transect.
4) Conduct Triaxus tows along selected transects.
5) Continue working along survey transects from west to east until survey is complete.

If the weather is not favourable, we may begin the CTD survey before we do the mooring deployment.

From the test station we go directly to the mooring site. We anticipate arriving in the night and will use this time to conduct a bathymetry survey and Triaxus tow, likely following a "lawnmower" pattern of five 30 km long transects spaced 5 km apart, but depending on the structure of the Polar Front based on sea surface height information. At daybreak the mooring operations will begin and should be completed by nightfall. We then conduct a triangulation operation to accurately survey the position of the mooring on the sea floor. We finish with a full-depth CTD/LADCP and VMP profile close to the mooring.

After the mooring we begin the meander survey. The survey will consist of eight cross-stream transects (~150 km in length) each with eleven evenly spaced CTD/LADCP stations. The meander is a very dynamic feature and so the precise location and orientation of the transects will be determined from satellite altimetry observations during the voyage. We will aim to have each transect cross the meander perpendicularly, with the centre of each transect near the fastest current flow (core of the jet) and even coverage north and south of the jet. Bottle samples will be analysed for salinity, oxygen, nutrients and chlorophyll. Some water will be taken for incubation experiments as required.

At each CTD/LADCP station along at least three of the transects, we will measure turbulent dissipation in the upper 2000m of the water column with a Rockland Scientific VMP2000. The transects will be located at the upstream edge, near the crest of the meander, and near the downstream edge. Most of the VMP deployments will be a single cast. At a few locations, multiple casts will be taken to estimate the variability in dissipation due to changes in the flow field in time at a single location and over small distances.

The 10 EM-APEX floats will be deployed at the western CTD transect. Each float deployment will follow a CTD/LADCP/VMP station. The shipboard data will provide valuable calibration information for the float data. The floats will drift through the CTD survey following streamlines of the meander flow. They will provide an exceptionally finely resolved view of the along-stream evolution of meander density and velocity structure over a period of approximately 100 days. The floats will continue to operate after the ship leaves the study site and will not be recovered. Their 5000 profiles will cover a wider area with more detail than the shipboard survey, giving for this shorter period a more comprehensive view of the meander's flow field.

High-resolution multi-beam bathymetry will provide exceptional detail of the sea floor along each transect. These data are essential for quantitative interpretation of the influence of topography on the internal wave and mixing variability in the profile data, and in understanding the relationship of the meander to the topography. The bathymetry is also essential for accurate initialization of the high-resolution simulations.

Underway measurements to be collected throughout the voyage will include upper ocean currents from shipboard ADCP (top 600 m), thermosalinograph measurements of surface temperature and salinity, and standard meteorological measurements including air temperature, pressure, wind velocity and high-resolution bathymetry. A maximum of 6 nutrient samples per day will be taken for hydrochemistry analysis.

Surface drifters will be deployed at various stations throughout the voyage. They can be thrown from the starboard aft quarter while the ship is steaming away from the station, or while underway.

Voyage track example

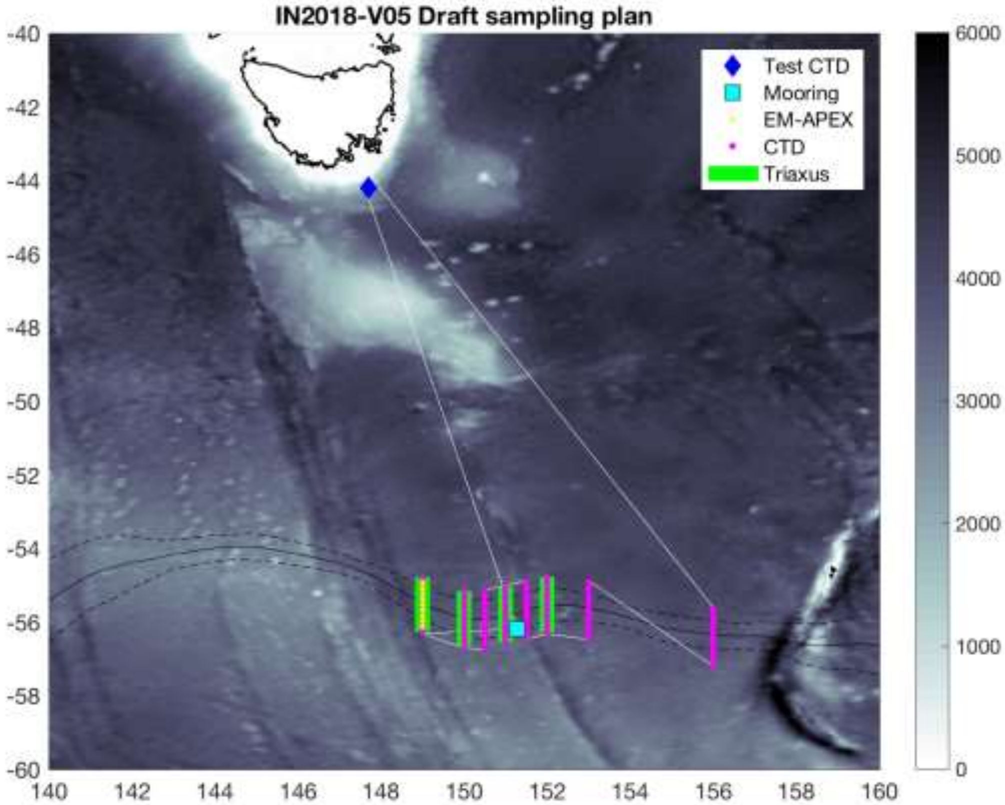


Figure 1. Intended voyage track and planned operations. Solid and dashed black contours are the mean latitude of the Polar Front (1992-2011) and 1 standard deviation either side. Shading is water depth (m) from Smith and Sandwell bathymetry. No multibeam data is available in this region (GSM Matt on IN2018_T01, personal communication).

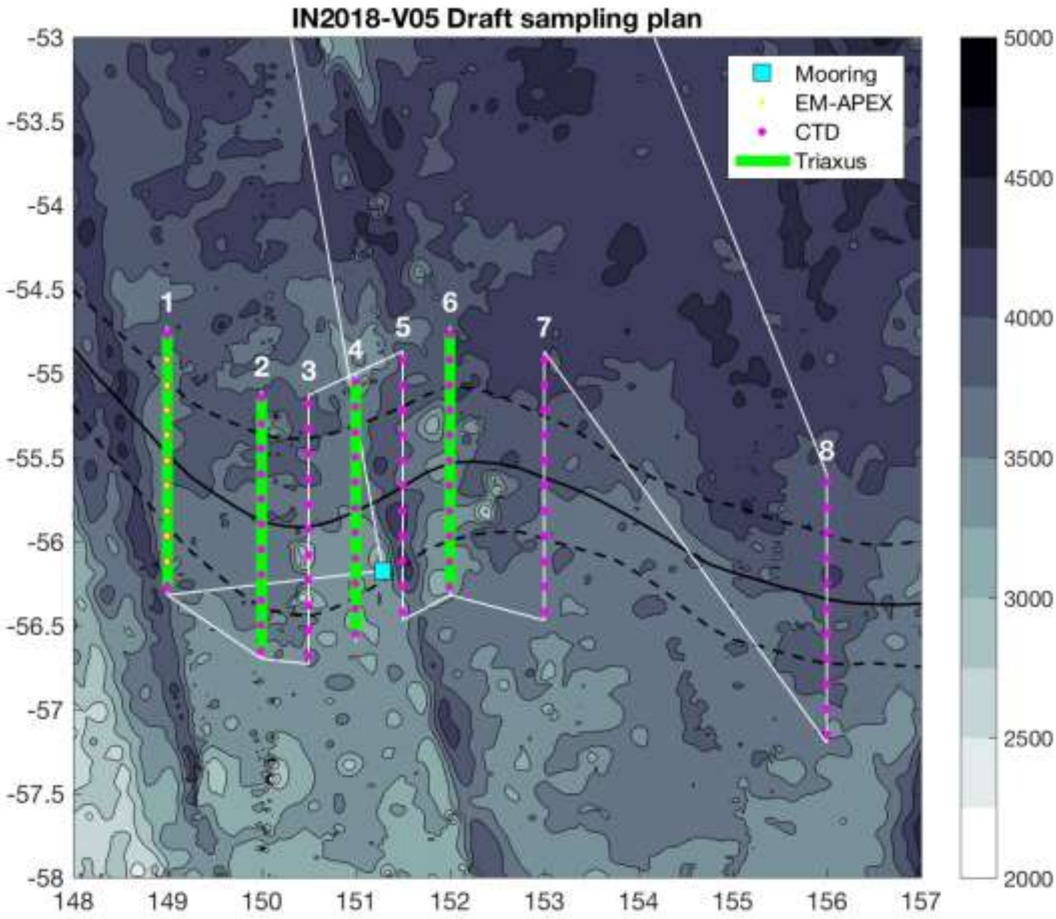


Figure 2. Detail of voyage track and operations shown in Figure 1.

Waypoints and stations

The following uses 11 knots ship speed to calculate steaming time, and 8 knots ship speed for Triaxus tows.

The timings are approximate and are subject to weather and operational revision. Waypoints for the meander survey and mooring are nominal. Waypoints will change to adapt to the changing position and structure of the Polar Front. We will receive daily updates of satellite sea surface height which we will use to track the front position. Waypoints will be reassessed and updated each day for the following 24 hour period.

Note that the purpose of this table is to list nominal waypoints and stations to be visited during the voyage. The distance and time between these waypoints is useful information but is not the total distance and time covered in the voyage. Full distance and time estimates are provided in the table on page 9 based on the voyage planning tool that produced Figures 1 and 2.

	Latitude (S)	Longitude (E)	Distance (nm)	Total Distance (nm)	Steaming time (hrs)	Total Steam (hrs)
Hobart	42° 52.2	147° 21.0				
Storm Bay	43° 19.8	147° 21.5	27.6	27.6	2.5	2.5
Test CTD	44° 12.0	147° 42.0	54.3	81.9	4.9	7.4
Mooring	56° 10.6	151° 17.1	731.6	813.5	66.5	74.0
Transect 1 South	56° 19.2	149° 0.0	76.7	890.2	7.0	80.9
Transect 1 North	54° 43.2	149° 0.0	96.0	986.2	8.7	89.7
Triaxus 1 South	56° 19.2	149° 0.0	96.0	1082.2	12.0	101.7
Triaxus 2 South	56° 42.0	150° 0.0	40.2	1122.4	5.0	106.7
Triaxus 2 North	55° 6.0	150° 0.0	96.0	1218.4	12.0	118.7
Transect 2 South	56° 42.0	150° 0.0	96.0	1314.4	8.7	127.4
Transect 3 South	56° 43.8	150° 30.0	16.6	1330.9	1.5	128.9
Transect 3 North	55° 7.8	150° 30.0	96.0	1426.9	8.7	137.6
Transect 4 North	55° 0.0	151° 0.0	18.9	1445.8	1.7	139.3
Transect 4 South	56° 36.0	151° 0.0	96.0	1541.8	8.7	148.0
Triaxus 4 North	55° 0.0	151° 0.0	96.0	1637.8	12.0	160.0
Transect 5 North	54° 52.2	151° 30.0	18.9	1656.7	1.7	161.7
Transect 5 South	56° 28.2	151° 30.0	96.0	1752.7	8.7	170.4
Transect 6 South	56° 19.2	152° 0.0	18.9	1771.6	1.7	172.1
Transect 6 North	54° 43.2	152° 0.0	96.0	1867.6	8.7	180.8
Triaxus 6 South	56° 0.0	152° 0.0	96.0	1963.6	12.0	192.8
Transect 7 South	56° 28.2	153° 0.0	34.4	1998.0	3.1	195.9
Transect 7 North	54° 52.2	153° 0.0	96.0	2094.0	8.7	204.6

Transect 8 South	57° 12.0	156° 0.0	172.2	2266.2	15.7	220.3
Transect 8 North	55° 36.0	156° 00.00	96.0	2362.2	8.7	229.0
Storm Bay	43° 19.8	147° 21.5	809.6	3171.9	73.6	302.6
Hobart	42° 52.2	147° 21.0	27.6	3199.5	2.5	305.1

Time estimates

The following time estimates are based on a steaming speed of 11 knots, and 8 knots ship speed for Triaxus tows.

The timings are approximate and are subject to weather and operational revision. Way points for the meander survey and mooring are nominal. Waypoints will change to adapt to the changing position and structure of the Polar Front. We will receive daily updates of satellite sea surface height which we will use to track the front position. Waypoints will be reassessed and updated each day for the next 24 hour period.

Date	Activity
16 Oct	Mobilise 1. Load gear for one tall mooring 2. Load EM-APEX profiling floats 3. Load biogeochemistry gear to internal labs (carry on) 4. Secure all gear in labs Aim to depart at 16:00 Testing of gear in Storm Bay, as required Arrive approx. 23:30 at test CTD location (-44.2 S; 147.7E - approx. 81 nm, 7.4 hours from Hobart). Conduct 1 full depth CTD and 1 VMP in 2000 m of water (4 hours).
17 Oct	Depart approx. 03:30 and begin transit to mooring location near 56.2 S; 151.3 E (732 nm 66.5 hours)
18 Oct	Steaming to mooring
19 Oct	Arrive at mooring 22:00 Conduct triaxus mapping around mooring location 5x15nm surveys (10 hours)
20 Oct	Approx. 08:00 begin mooring operations Approx 17:00 end mooring operations, including triangulation of mooring location Conduct full depth CTD and VMP (approx. 4.5 hours) Depart approx. 21:30 and begin transit to start of CTD transect 1 near 56.32 S; 149 E – approx. 77nm, 7 hours
21 Oct to 12 Nov	Arrive approx. 04:30 at southern end of CTD Transect 1 Begin meander survey Transect 1 11 CTD/LADCP+VMP stations from south to north; EM-APEX deployments after VMP; Triaxus tow north to south; Triaxus to Transect 2 south Transect 2 Triaxus tow south to north; 11 CTD/LADCP stations from north to south; steam to Transect 3 south

Date	Activity
	Transect 3 11 CTD/LADCP stations from south to north; steam to Transect 4 north Transect 4 Triaxus tow north to south, 11 CTD/LADCP stations from south to north; steam to Transect 5 north Transect 5 11 CTD/LADCP stations from north to south; steam to Transect 6 south Transect 6 Triaxus tow south to north, 11 CTD/LADCP stations from north to south; steam to Transect 7 south Transect 7 11 CTD/LADCP stations from south to north; steam to Transect 8 south Transect 8 11 CTD/LADCP + VMP stations from south to north End of survey Total survey time = 545 hours (22.7 days) Steaming within survey = 1472 nm, 133.8 hours CTD time = 278 hours - 88 stations x (4000m depth x 2 @ 60m/min + 20 mins setup + 36 mins bottle soak) VMP time = 55 hours - 33 stations x (1 hour profile + 40 minute setup) Weather time = 74 hours Triaxus extra time = 16 hours – (4 x 100nm tows at 8 kn instead of 12kn + 1 hour setup/recovery)
13 Nov	Approx. 08:00 Depart northern end of Transect 8. Steam to Hobart - 837 nm, 76 hours (3.2 days)
16 Nov	Arrive Hobart approx. 10:30 Demobilise

Supplementary Project

Upper ocean biogeochemistry in the Macquarie Meander of the Antarctic Circumpolar Current
Dr Peter Strutton, IMAS, University of Tasmania
This supplementary project will assess the biogeochemical impact of the physical braking of the ACC, which will likely manifest in vertical mixing of nutrients and an impact on surface productivity. The proposed work compliments IN2016_V02, which mapped the biogeochemical impact of two eddies in almost the same region of the Southern Ocean. The work therefore adds value to the previously-awarded MNF ship time by surveying the biogeochemistry in a meander similar to where the IN2016_V02 eddy would have formed, as well as adding a biogeochemistry dimension to

IN2018_V05. The results will deepen our understanding of nutrient delivery and consumption in the Southern Ocean, with benefits for future climate models.

The aims of this supplementary work are to:

1. Characterise the nutrient field in the context of the physical structure of the meander (the nutrient measurements are included in the original voyage proposal).
2. Calculate rates of nutrient delivery to the surface.
3. Contrast the relative importance of upwelling and mixing with previous nearby measurements.

Before the voyage, we will monitor satellite altimetry, SST and chlorophyll data to understand the real time dynamics of the meander. We will also establish automated scripts to forward satellite data to us at sea, daily, as we did for IN2016_V02.

During the transit to the sampling area for IN2018_V05, we may request a deviation to the ship track to sample an eddy, **only if practical and agreed to by the chief scientist**. This will only happen if an interesting eddy has been identified in the pre-voyage satellite data. We will be able to plan for this before leaving port. If such an eddy is found, and time permits, we would like to sample it with surface underway measurements.

During IN2018_V05's CTD grid, we will supplement the program already proposed by the lead project, by taking biogeochemical samples from about 25% of all CTD stations. This will add time to the sampling of the CTD rosette once it is on deck, but the transit time between proposed CTDs is about 1 hour. Our sampling will not delay CTD deployments or slow the rate at which stations can be completed. The following samples will be taken:

Nutrients: The lead project has requested staffing by the MNF hydrochemistry team sufficient to run nutrients, salinity and dissolved oxygen from the CTDs. We would like to use these data.

Phytoplankton pigments: About 0.5L per depth from 0 to 200m for chlorophyll and an additional 1.0L for occasional HPLC pigments.

Particulate organic carbon (POC): About 1.0L from 3 depths per CTD to calibrate the CTD transmissometer for POC.

Incubation experiments: About 2.0L per depth from 6 depths between 0 and 200m to measure phytoplankton growth through incubations on deck.

Investigator equipment (MNF)

1. Triaxus
2. Deck incubators

User Equipment

Item name	Supporting information
EM-APEX Floats	10 Argo float sized instruments in wooden crates (H. Phillips, UTAS)
VMP-2000	Vertical Microstructure Profiler (K. Polzin, WHOI)
Surface drifters	To be provided by NOAA Global Drifting Buoy Program (S. Dolk, NOAA)

Camera Equipment	Sarah Lanier, Ocean Media Institute.
Mooring Equipment	Diagram provided at the end of this document.

Special Requests

1. Real-time data downloads

The Polar Front moves around a lot and eddies are formed within it. To get a good survey we need to have daily updates of real-time satellite data. This includes sea level anomaly, sea surface temperature, sea surface salinity, satellite winds, satellite chlorophyll.

We may also need to download model simulations from our shore-based PI Max Nikurashin.

2. Installation of VMP winch onto aft deck

Kurt Polzin and Brett Muir are working on details for the VMP operation. The most likely arrangement is that the VMP will be deployed from the aft deck. The VMP comes with a self-contained deployment setup of winch and line, winch motor, and profiling instrument. The VMP is stored inside the wet lab until on station. It is carried to the aft deck by 2 people and connected to the line under the A-frame. The VMP line is run through a block on the A-frame and back to the winch, which is bolted to the deck in a position determined by MNF. The VMP is lowered into the water and then is allowed to free-fall to its maximum depth of 2000m while the ship moves very slowly ahead. This is to ensure the line remains aft of the ship. Once the VMP is recovered, it is carried back to the wet lab for data download and battery charging through the ship's mains power. An alternative deployment procedure using the light coring winch is also being discussed by Brett and Kurt.

Permits

This work is all in international waters and there are no permits required.

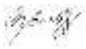
Personnel List

	Name	Role	Institution
1.	Don McKenzie	Voyage Manager	CSIRO MNF
2.	Brett Muir	SIT Support	CSIRO MNF
3.	Will Ponsonby	SIT Support	CSIRO MNF
4.	Stuart Edwards	GSM Support	CSIRO MNF
5.	Phil Van Den Bossche	GSM Support	CSIRO MNF

6.	Pamela Brodie	DAP Support	CSIRO MNF
7.	Peter Shanks	DAP Support	CSIRO MNF
8.	Dion Frampton	Hydrochem	CSIRO MNF
9.	Julie Janssens	Hydrochem	CSIRO MNF
10.	Mark Rayner	Hydrochem	CSIRO MNF
11.	Peter Hughes	Hydrochem	CSIRO MNF
12.	Nathan Bindoff	Chief Investigator	University of Tasmania
13.	Helen Phillips	Principal Investigator	University of Tasmania
14.	Kurt Polzin	Principal Investigator	Woods Hole Oceanographic Institution, USA
15.	Jamie Derrick	Mooring Technician	CSIRO
16.	Mark Rosenberg	Seagoing Technician	Antarctic Climate and Ecosystems CRC
17.	Jan Jaap Meijer	IMAS PhD Student	University of Tasmania
18.	Benoit Legresy	Research Scientist	CSIRO
19.	Sarah Lanier	Communications expert - Filmmaker	Ocean Media Institute www.oceanmediainstitute.org
20.	Annalise Rees	Artist and Communicator	University of Tasmania
21.	Annie Foppert	Postdoctoral Fellow	CSIRO Oceans and Atmosphere
22.	Veronica Tamsitt	Postdoctoral Fellow	CSIRO Oceans and Atmosphere
23.	Jorlyn Legarrec	Student of Craig Stevens	NIWA/University of Wellington
24.	Laura Eischens	Student of John Abraham	University of St Thomas, Minnesota
25.	Matthew Endres	Senior geology student	University of St Thomas, Minnesota
26.	Brian Kaiser	Postgrad Student	Woods Hole Oceanographic Institution, USA
27.	Ramkrushn Patel	Student	IMAS/UTas
28.	Josue Martinez Moreno	Centre of Excellence student	ANU
29.	Nicholas Yeung	Centre of Excellence student	UNSW
30.	Saurabh Rathore	Centre of Excellence student	IMAS
31.	Ajitha Cyriac	Centre of Excellence student	IMAS

32.	Abhishek Savita	Centre of Excellence student	IMAS
33.	Nicky Wright	Centre of Excellence student	ANU
34.	Vidhi Bharti	Air-Sea Fluxes Centre of Excellence student	Monash
35.	Roseanna McKay	Centre of Excellence student	Monash
36.	Natasha Gafar	Piggy-back personnel	UTas
37.	Nic Pittman	Piggy-back personnel	UTas
38.	Clara Rodriguez-Vives	Piggy-back personnel	UTas

Signature

Your name	Prof Nathan Bindoff
Title	Chief Scientist
Signature	
Date:	30/08/2018

List of additional figures and documents

Mooring diagram added at the end of the document.

Scientific equipment and facilities provided by the Marine National Facility

Some equipment items on the list may not be available at the time of sailing. Applicants will be notified directly of any changes.

Indicate what equipment and facilities you require from the Marine National Facility by placing an **X** in the relevant box.

(i) Standard laboratories and facilities

Name	Essential	Desirable
Aerosol Sampling Lab		
Air Chemistry Lab		
Preservation Lab		
Constant Temperature Lab		
Underway Seawater Analysis Laboratory	X	
GP Wet Lab (dirty)	X	
GP Wet Lab (Clean)	X	
GP Dry Lab (Clean)	X	
Sheltered Science Area	X	
Observation deck 07 level		
Walk in Freezer	x	
Clean Freezer		
Blast Freezer		
Ultra-Low Temperature Freezer	x	
Walk in Cool Room		

(ii) Specialised laboratory and facilities

(May require additional support)

Name	Essential	Desirable
Modular Radiation Laboratory		
Modular Trace Metal Laboratories		
Modular Hazchem Locker		
Deck incubators	x	
Stabilised Platform Container		

(iii) Standard laboratory and sampling equipment

Name	Essential	Desirable
CTD - Seabird 911 with 36 Bottle Rosette	X	
CTD -Seabed 911 with 24 Bottle Rosette		X
LADCP	X	
Sonardyne USBL System		
Milli -Q System	X	
Laboratory Incubators		
Heavy Duty Electronic Balance		
Medium Duty Electronic Balance		
Light Duty Electronic Balance		
Surface Net		
Bongo Net		
Smith Mac grab		
Dissecting Microscopes		

(iv) Specialised laboratory and sampling equipment

(May require additional support)

Name	Essential	Desirable
TRIAXUS – Underway Profiling CTD	X	
Continuous Plankton Recorder (CPR)		
Deep tow camera		
Piston Coring System		
Gravity Coring System		
Multi Corer		
XBT System	X	
Trace Metal Rosette and Bottles		
Sherman epibenthic sled		
Trace- metal in-situ pumps		
Rock Dredges		
EZ Net		
Rock saw		
Portable pot hauler		
Beam Trawl		
Trawl doors (pelagic or demersal)		
Stern Ramp		

Trawl monitoring instrumentation (ITI)		
Radiosonde		

(v) Equipment and sampling gear requiring external support

(May require additional support from applicants)

Name	Essential	Desirable
Seismic compressors		
Seismic acquisition system		

(vi) Underway systems

Acoustic Underway Systems

Name	Essential	Desirable
75kHz ADCP	X	
150kHz ADCP	X	
Multi Beam echo sounder EM122 12kHz (100m to full ocean depth)	X	
Multi Beam echo sounder EM710 70-100kHz (0-1000m approx.)		X
Sub-Bottom Profiler SBP120		
Scientific Echo Sounders EK60 (6 bands, 18kHz-333kHz)		
Gravity Meter		
Trace metal clean seawater supply		

Atmospheric Underway Sensors

Name	Essential	Desirable
Nephelometer		
MAAP (multi angle absorption photometer)		
SMPS (scanning mobility particle sizer)		
Radon detector		
Ozone detector		
Manifold instrumentation (intake temperature and humidity)		
Picarro spectrometer (analysis of CO_2/CH_4/H_2O)		
Aerodyne spectrometer (analysis of N_2O/CO/H_2O)		
O2 analyser		
Manifold instrumentation (intake temperature and humidity)		
CCN (Cloud Condensation Nuclei)		
MOUDI (Micro-Orifice Uniform Deposit Impactors)		
NOx monitor		
Polarimetric Weather Radar		

Underway Seawater Instrumentation

Name	Essential	Desirable
Thermosalinograph	X	
Fluorometer	X	
Optode	X	
PCO2	X	

Mooring diagram as developed by Peter Jansen, CSIRO.