RV *Investigator* Voyage Summary

Voyage #:	IN2019_T02
Voyage title:	Deep seascapes of the Great Barrier Reef: Uncovering submarine canyons and landslides
Mobilisation:	Brisbane, Wednesday 2nd – Thursday 3rd October 2019
Depart:	Brisbane, 0500 Friday, 4th October 2019
Return:	Darwin, 0900 Monday, 14th October 2019
Demobilisation:	Darwin, Monday, 14th October 2019
Voyage Manager:	S. Thomas
Chief Scientist:	R. Beaman
Principal Investigators:	R. Beaman
Project name:	Deep seascapes of the Great Barrier Reef: Uncovering submarine canyons and landslides
Affiliation:	James Cook University
Principal Investigators:	Dr D. Erler
Project name:	First measurements of nitrate isotopic composition in the Coral Sea
Affiliation:	Southern Cross University
Principal Investigators:	Dr E. Woehler
Project name:	Spatial and temporal variability in the distribution and abundance of seabirds
Affiliation:	University of Tasmania
Principal Investigators:	Dr A. Protat
Project name:	ORCA: Using the *Investigator* radar as a moving reference for the Australian operational radar network
Affiliation:	Bureau of Meteorology
Principal Investigators:	Dr R. Przeslawski
Project name:	Environmental baselines for Wessel Marine Park, northern Australia
Affiliation:	Geoscience Australia

Voyage Summary

Objectives and brief narrative of voyage

This transit voyage from Brisbane to Darwin consisted of five individual supplementary projects, along with an additional four piggyback projects, which were undertaken during the 48 hours of science time allocated, either while the vessel was transiting or on station.

Mapping of submarine canyons and landslides occurred along the vessel's entire transit along the GBR margin, and detailed site surveys were conducted at three sites of interest. Each waypoint of the voyage track was chosen specifically in order to further fill in gaps in bathymetric data along the voyage route.

Six CTD stations were conducted, along with underway seawater sampling across the duration of the transit. *Trichodesmium* samples were collected at all six CTD stations, and 2x BGC-Argo floats were deployed at the first CTD station.

Seabird and marine mammal observations occurred continuously during daylight hours across the entire duration of the transit.

The Wessel Marine Park project aimed to acquire seabed and habitat data using multibeam and towed imagery to further understand and manage a data-poor marine park. This survey focussed on an interesting geological hole feature, completing its high-resolution mapping and identifying a highly localised community of habitat-forming suspension feeders around the edge and slope of the hole. In addition, onboard Parks Australia staff shared our results with the local Traditional Owner who expressed strong interest and appreciation for seeing her Sea Country first-hand.

Scientific objectives

Supplementary Project 1: Deep seascapes of the Great Barrier Reef: Uncovering submarine canyons and landslides (Beaman)

The overall aim is to better understand the deep (>100 m) underwater landscapes (or seascapes) of the Great Barrier Reef (GBR) by determining the spatial extent, character and timing of the primary erosive features that have sculpted the GBR margin: the submarine canyons and landslides.

Our group has been actively mapping the GBR slope since 2007 when we first discovered the complex canyon system incising this margin (Webster et al., 2008). We have since been steadily improving the multibeam data coverage using MNF and foreign research vessels to reveal over 100 canyons stretching from the central GBR to the far northern GBR and Torres Strait. The aggregated bathymetry data are publicly available as the gbr100 grid.

We have previously conducted extensive research on these canyons and their role as conduits for sediments transported from the shelf to basin. This research includes canyon morphology and controls on their evolution (Puga-Bernabéu et al., 2011), turbidite sedimentation in a large canyon (Webster et al., 2012), the influence of slope gradient and reefs on canyons (Puga-Bernabéu et al., 2013), and the 60 kyr record of regional-scale turbidites (Puga-Bernabéu et al., 2014).

We have also discovered many small lower-slope landslides associated with these canyons, but also much larger landslides. Research on these landslides includes potential collapse features and tsunami generation (Puga-Bernabéu et al., 2013), a detailed study of an upper-slope landslide (Webster et al., 2016), the largest landslide on the GBR margin (Puga-Bernabéu et al., 2017), and landslide relationships to shelf-edge deltas (Daniell et al., in prep).

Yet many gaps in the data and our understanding remain. Detailed multibeam data are lacking in places opposite the Ribbon Reefs, where most of our canyon research has taken place. The larger landslides on the central GBR margin also lack geomorphic detail on their debris field extents and runout distances. The far northern GBR margin was lacking almost any canyon detail until we conducted a voyage on the German RV *Sonne* in 2017.

The scientific objectives are to combine the geophysical data collected from this voyage, with previously collected bathymetric and sub-bottom profile data and sediment cores to:

(A) Improve the bathymetric datasets available for the GBR continental slope and construct a comprehensive new inventory of the key landslides and canyons and their detailed geomorphic traits.

(B) Provide information at the regional-scale regarding the sedimentary processes and evolution of the margin, as a crucial first step towards understanding landslide susceptibility, tsunami hazard and improved risk assessments.

(C) Characterise the canyon systems on the far northern GBR to allow comparisons with the better-studied canyons on the central GBR, with respect to their geomorphic variability, gradients and relationship to shelf-edge reefs.

(D) Provide new data to construct and validate numerical, basin-scale, stratigraphic forward models used to test sedimentary source-to-sink processes in this mixed siliciclastic-carbonate setting.

(E) Provide the site survey data for a future International Ocean Discovery Program (IODP) Ancillary Project Letter (APL) proposal, to core the canyon deposits and recover coarse-grained, shallow-water carbonate sediments shed from the shelf, to better constrain the timing of the onset of the GBR.

<u>Supplementary Project 2: First measurements of nitrate isotopic composition in the Coral Sea (Erler)</u>

Upwelling is known to be an important source of nitrate to the outer reef ecosystems of the Great Barrier Reef (GBR). However, the frequency and duration of upwelling events, as well as the penetration of nitrate rich water into the GBR lagoon is poorly understood because of a lack of long-term records. The objective of this project is to improve our understanding of upwelling onto the continental shelf.

<u>Supplementary Project 3: Spatial and temporal variability in the distribution and abundance of seabirds (Woehler)</u>

The project seeks to quantify the distribution and abundance of seabirds and marine mammals at sea around Australia using standardised seabird survey protocols. Dedicated observers will collect real-time data on seabirds observed within 300m transect during daylight hours while the vessel is underway. Incidental observations will be collected while the vessel is stationary. The data collected will be compatible with previous seabird at sea surveys conducted around Australia and farther south, allowing for analyses and assessments to be extended by the current surveys. The distribution of seabirds at sea is strongly linked with oceanographic features such as convergences that concentrate prey at densities that allow for efficient foraging by seabirds. Our surveys on the voyage will link with oceanographic investigations to identify the types and strengths of oceanographic features at which we observe different species of seabirds that utilise different methods of feeding (surface seizing, diving etc). No dedicated ship time is required for the seabird surveys. Surveys are conducted by observers while the vessel is underway during daylight hours.

Supplementary Project 4: ORCA: Using the *Investigator* radar as a moving reference for the Australian operational radar network (Protat)

The aim of the Optimizing Radar Calibration and Attenuation corrections (ORCA) project is to use the *Investigator*'s C-band Doppler dual-polarization weather radar (OceanPOL) and OceanRAIN ODM470 disdrometer as moving references to: (1) Evaluate (and if needed improve) the calibration of selected coastal radars from the BOM operational weather radar network and investigate some aspects of these calibration techniques further; and (2) Characterise the regional variability of the so-called self-consistency dual-polarization calibration relationship using disdrometer observations for use in future operational calibration techniques.

Our second objective is to develop C-band attenuation corrections for OceanPOL using unattenuated collocated S-band ground-based radar measurements from the operational radar network collected during the transit voyages. This objective cannot be addressed with data collected on this voyage (no storms) but should be during the later Darwin – Fremantle transit voyage (IN2019_T03).

Supplementary Project 5: Environmental baselines for Wessel Marine Park, northern Australia (Przeslawski)

This project aims to collect and analyse valuable environmental baseline information in a data-poor marine park. Specifically, we will use a combination of multibeam sonar and towed imagery to map the seafloor and characterise seafloor habitats in a northern area in the Wessel Marine Park region.

Collected data will be combined with the limited data available from previous surveys, as well as museum records, to test assumptions about the Wessel Marine Park drawn from the 2018 management plan. These assumptions are:

(A) Includes some of the most diverse environments in the North Marine Region.

(B) Includes some of the most species-rich environments in the North Marine Region.

(C) Supports a number of endemic species.

(D) Acts as a transition point for sessile invertebrate and fish species.

In addition, we will test the hypothesis that the raised seabed features (banks, shoals) in the park are relict reefs that formed at lower sea levels in the early Holocene period (ca. 12,000 to 7,000 years before present).

Results from this study will inform detailed implementation plans to be developed by the Department of Environment and Energy over the next 10 years. In particular, this study will expand the currently limited species inventory from the region, contribute to an assessment of the significance of raised geomorphic features in the park, and identify geomorphic features, habitats, or communities of interest.

Voyage objectives

Supplementary Project 1: Deep seascapes of the Great Barrier Reef: Uncovering submarine canyons and landslides (Beaman)

Equipment and operations

EM122 and EM710 multibeam swath data will be collected to obtain bathymetry and backscatter coverage of the submarine landslides and canyons to understand their spatial distribution, geomorphic character and surficial sedimentation patterns. Water column data will be acquired to identify if any demersal fish or plankton layers are associated with the landslides or canyons.

SBP120 sub-bottom profile data will also be collected to provide additional context for the nature of near-surface sediment and geological structure of the submarine landslides and canyons. Equipment will be utilised continuously for duration of the transit. The MNF GSM team will be assisted through the 12-hour shifts by the science team students and PIs.

Multibeam data will be edited for noise, sound velocity applied and GPS tides applied to the raw data. 3D visualisation of the various slope features will be constantly updated using a combination of Fledermaus, CARIS, ArcGIS/QGIS and GMT software. The aim is to have multibeam data completely edited by the time of arrival in Darwin.

Sound velocity profiles will be obtained by XBTs dropped along the way, SVP deployments and from any CTD profiles.

Sub-bottom profile data will be constantly updated to a dedicated Kingdom software project for fine-scale examination of sub-surface features. The aim is to have a fully interpreted Kingdom project completed by the time of arrival in Darwin.

General survey

The voyage will transit along the GBR continental slope and target four areas of interest (Figure 1). These waypoints have been carefully chosen to survey the key landslides and canyons of interest, while minimising excessive deviations from the general track taken from Brisbane to Darwin. Waypoints have also been selected to obtain swath data that overlaps slightly with previous multibeam tracks, thereby extending the area of the slope surveyed.

Areas of interest

Four particular areas of interest along the GBR slope are the Swain slide, Bowl slide, Stapleton canyons, and Clack canyons (named for their proximity to particular reefs). Waypoints have been selected to carefully survey these areas to achieve near-100% seabed coverage in order to understand their full spatial distribution and geomorphic character (Figure 1).

Should time not permit all these surveys to be completed (e.g. poor weather), then the largest survey, Clack canyons, could be truncated or abandoned to enable the *Investigator* to be on time in Darwin.

Timing

The proposed waypoints along the Queensland margin (Leg1 WP 1 to WP 65) have a combined distance of 1476.64 nm. Planned at 11 kn, this distance equals 134.24 hours or 5.6 days. The allocated 15 hr (five CTDs) and 3 hr (radar calibration) for Supplementary Projects along the GBR margin add an additional 18 hr, equalling 152.24 hr or 6.34 days between Leg1 WP 1 to WP 65.

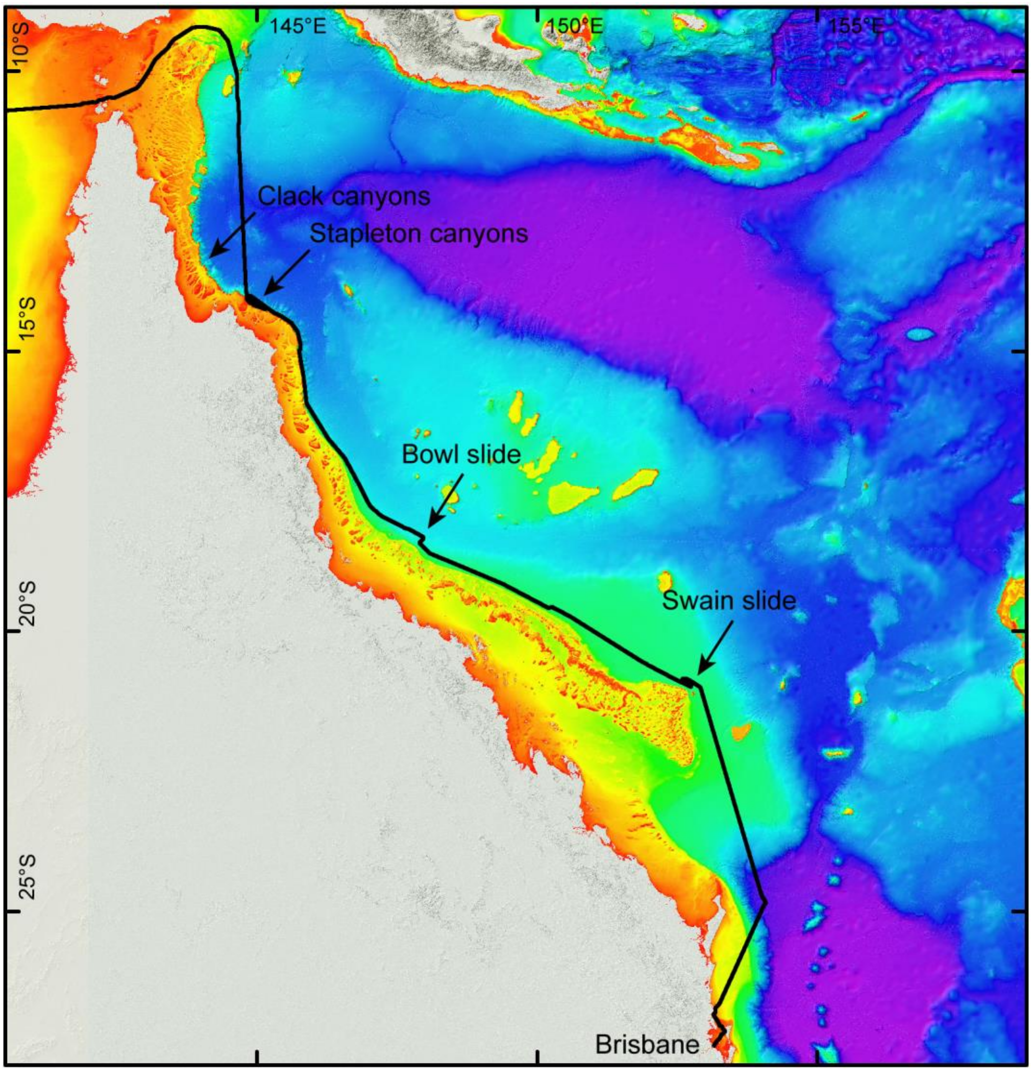

Figure 1. Plan view map of voyage IN2019_T02 from Brisbane along the GBR slope, showing the four areas of interest: Swain slide, Bowl slide, Stapleton canyons and Clack canyons survey areas.

Supplementary Project 2: First measurements of nitrate isotopic composition in the Coral Sea (Erler)

Equipment and operations

Nitrate is the most prevalent inorganic form of inorganic nitrogen in the Coral Sea. A number of previous cruises have measured the concentration of nitrate in the Coral Sea, but none have measured its isotopic composition. The method for the collection of nitrate isotope samples is identical to the sampling of nutrients and is performed using a Niskin bottle and a high resolution CTD logger (to determine the exact depth that samples are collected at). Samples are collected at multiple depths, and based on the data from previous cruises, the best approach would be to collect samples every 50 m down to 500 m. When water samples reach the surface, they are filtered into acid washed bottles and frozen immediately. I anticipate that water sample collection will take approximately 3 - 5 hours per site. Samples must be kept frozen and I will need to use either ice packs or dry ice to keep samples frozen at the completion of the cruise. Ideally, I would like collect samples from 5 locations along the continental shelf adjacent to the GBR (south to north).

In addition to the nitrate isotope samples, additional samples will be taken for nitrous oxide concentration and isotopic composition. There are no measurements of nitrous oxide concentration or isotopic composition for deep ocean water in the Coral Sea. This data will help constrain the nitrous oxide flux during upwelling. To further constrain this budget, we plan to perform continuous measurements of nitrous oxide concentration in surface waters during transit. This will be performed with a Picarro greenhouse gas analyser coupled to a gas exchange system.

Areas of interest

Five sites have been selected along the Queensland margin:

Site	Decimal Latitude	Decimal Longitude	Latitude	Longitude	Location
1	24° 52.32	154° 03.16	-24.8720000	154.0527000	Fraser Island
2	20° 31.01	151° 49.94	-20.5168400	151.8323877	Swain Reefs
3	18° 41.99	148° 18.19	-18.6998913	148.3031412	Central GBR
4	15° 42.40	145° 51.61	-15.7066123	145.8601516	Ribbon Reefs
5	11° 11.01	144° 06.46	-11.1834874	144.1076977	Cape York

Table 1. Five sites for CTD nitrate sampling (see Figures 1 and 2).

Timing

Three hours are allocated for each CTD site, hence 15 hours are planned with the vessel stationary.

<u>Supplementary Project 3: Spatial and temporal variability in the distribution and abundance of seabirds (Woehler)</u>

Equipment and operations

Seabird at sea data will be collected according to the method described by the BIOMASS Working Party on Bird Ecology. This method has been used by Australian Antarctic Division (AAD) personnel since 1980/81 and reflects the standard protocol for obtaining seabird at sea data.

Observations will be made continuously while the vessel is underway during daylight hours from the specifically designed Observation Deck onboard *Investigator*. It is hoped that three seabird observers will be placed on the nominated Research and Transit Voyages.

Briefly, all seabirds within a 300 m forward quadrant will be recorded, with details of their ages (where identifiable) and behaviours (such as feeding, sitting on water etc.). By using standard methods, the data collected on these voyages will be able to be integrated with other datasets collected adjacent with, or in overlapping areas (e.g. Australian Antarctic Division surveys 1980/81 onwards).

Observations of marine mammals are also included (in the absence of dedicated marine mammal observers) using standard protocols. Observation of marine debris are also recorded.

Data will be entered in real time on laptops connected to the ships oceanographic and GPS system to automatically record abiotic and biotic data alongside seabird observational records. Standardised methods of data collection ensure continuity and compatibility with extant data for the same species elsewhere and with similar studies of other species.

No equipment is required, apart from access to the Observation Deck on Level 7.

Areas of interest

The seabird observation program is passive and has no influence on the ship track.

Timing

The observation program is undertaken continuously during daylight hours from *Investigator*.

Supplementary Project 4: ORCA: Using the *Investigator* radar as a moving reference for the Australian operational radar network (Protat)

Equipment and operations

For the ORCA project, the voyage objectives are to collect *Investigator* C-band Doppler dual-polarization weather radar (SEAPOL) and OceanRAIN ODM470 disdrometer observations of precipitation collocated with as many radars from the BOM operational radar network located along the coast from Brisbane to Darwin in an opportunistic manner. When no precipitation is present, we will make use of the SEAPOL radar data in clear air to compare ground clutter measurements along the coast. This project will require a non-standard radar configuration for the *Investigator* radar, which will replicate that of the operational weather radar (14 elevations on a 6-minute cycle). This scanning strategy will be introduced in the radar control software before the ship leaves port (by Will Ponsonby, MNF, and Alain Protat).

Areas of interest

Anytime the ship will be close enough (<150 km) from a coastal radar of the operational network, we will collect measurements useful for the ORCA project. Brisbane, Townsville, Cairns, Warruwi and Darwin should be our main opportunistic targets:

Radar	Decimal Latitude	Decimal Longitude
Brisbane	27° 43'	153° 14'
Townsville	19° 25'	146° 33'
Cairns	16° 49'	145° 41'
Warruwi	11° 39'	133° 23'
Darwin	12° 28'	130° 56'

Table 2. Coastal radar sites.

Timing

We would like to request that the Chief Scientist consults on behalf of PI Protat (who is not going on the ship) with the Master, Voyage Manager and PIs onboard to agree to stop the vessel and stay on station for one hour if there is precipitation when the vessel is within 150 km of the Brisbane, Townsville, Cairns, Warruwi or Darwin radars. As there are only three hours allocated to our ORCA project, this can only be done for three of these five radars, at the discretion of the lead Chief Scientist and onboard Management Team.

Supplementary Project 5: Environmental baselines for Wessel Marine Park, northern Australia (Przeslawski)

Equipment and operations

Multibeam operations will be undertaken during the first 6 hours to acquire continuous high-resolution bathymetry and backscatter data in the study area. Data will be acquired with the *Investigator*'s EM710 according to the MNF's current protocols and supplemented by the *Seafloor Mapping Field Manual for Multibeam Sonar*. Anticipated speed during multibeam acquisition will be 8 knots but will be adjusted as needed according to sea state and heading. Beam width at a depth of 60 m in the study area will be ~140 m, with 30% overlap.

Towed imagery stations will be confirmed using mapping from multibeam operations. Towed imagery operations will follow national consistent protocols from the *Marine Sampling Field Manual for Towed Underwater Camera Systems*, with the exception of the recommended downward-facing stills camera to be substituted with the forward-facing stills camera on the *Investigator*'s deep-tow system.

The camera will be deployed for 1000 m (~30 minutes bottom time at 1 knot) along depth and geomorphic gradients along each sampling transect. Real-time video footage will be characterised using a qualitative habitat characterisation to identify transition zones. This will provide an immediate characterisation of habitat, while annotation of the still images undertaken during the post-processing will provide a quantitative assessment.

Areas of interest

The Wessel Marine Park is located off the remote coast of northern Australia, adjacent to Cape Wessel and the surrounding archipelago. The marine park overlaps an Indigenous Protected Area (IPA) due to its significance to local indigenous communities and efforts to protect and monitor the health of culturally significant and threatened species.

The Marine Park and its surrounding waters adjacent to the transit route and the Wessel Islands are considered a biodiversity hotspot, thought to support a number of endemic species, as well as a variety of unique sponge and coral communities.

We will focus on a northern grid immediately adjacent to the transit route and the Wessel Marine Park. This grid will expand on previous mapping in 2005 and biological sampling in 2013 undertaken over a deep hole and possible terrace. If the transit voyage is well ahead of schedule, we will instead undertake mapping and camera operations within a grid in the centre of the Habitat Protection Zone of the Wessel Marine Park.

Timing

Multibeam operations will commence immediately upon arrival at the Wessel Marine Park region, with continuous multibeam coverage generated for six hours and used to inform the subsequent towed imagery.

Piggyback Projects

Trichodesmium sampling (Hawker)

Trichodesmium is an important but poorly understood part of the marine environment. It is thought to be responsible for a significant majority of nitrogen fixation in the ocean; understanding its habitat and range is therefore an important part of understanding ocean primary productivity. Around Australia, *Trichodesmium* is most commonly seen along the northern Queensland coast. However, knowledge of *Trichodesmium* is relatively scarce as it is impossible to culture in laboratory studies and difficult to accurately observe in-situ. Basic questions such as the spatial patterns and seasonal cycles of *Trichodesmium* remain poorly understood.

This project aims to contribute to the observational record of *Trichodesmium* by collecting and analysing seawater samples at locations adjacent to the Great Barrier Reef. Surface samples will be collected at existing planned CTD cast locations, so there will be no impact on the voyage track or scheduling. These observations will assist researchers to answer those questions outlined above. They will also aid in the verification of *Trichodesmium* remote sensing algorithms, as well as biogeochemical ocean forecast systems such as the eReefs.

Sampling will include:

1. A 200 mL sample from the surface during CTD casts for isolation and culturing of *Trichodesmium.* The samples are decanted into 250 mL tissue culture flasks and kept under normal light at room temperature (20°C)
2. A sample (50 mL) from the surface filtered through 0.2 µm Sterivex filters during CTD casts for genetic analysis of *Trichodesmium*. Filters should be labelled with station, CTD number, volume of sample filtered and then bagged and frozen at -80°C.
3. Samples collected from the Continuous Plankton Recorder (CPR), see below for methodology.

AIR-BOX integration and calibration (Schofield)

The integration and calibration of the AIR-BOX (a containerised laboratory which houses aerosol atmospheric monitoring instruments), guest instruments in the aerosol laboratory and air chemistry laboratories, as well as optical instruments located on deck 5, will occur during this voyage. This is in preparation for the upcoming voyage IN2019_V06, during which the AIR-BOX will be utilised in conjunction with RV *Investigator*'s aerosol laboratory and air chemistry laboratory to continuously collect comprehensive atmospheric chemistry and aerosol measurements.

PI Schofield will coordinate with the AIR-BOX consortium to conduct atmospheric biogenic air measurements, aerosol composition, aerosol profile and oxidative capacity measurements to understand the emissions and processing of sulphur and halocarbons from the ocean in this region. Trace-gas and aerosol observations near the Great Barrier Reef will be made continuously throughout this transit voyage.

Continuous Plankton Recorder (CPR) sampling will also occur in conjunction with the AIR-BOX measurements. The CPR will be deployed during the longer legs of the transit (i.e. between CPR deployments and mapping surveys). CPR deployments will also be scheduled around the deployments of other towed equipment (e.g. SVPs). One cassette can be used to sample plankton on tows of up to 450 nm. Where the cassette is towed for <450 nm (i.e. the vessel is required to stop for a CTD deployment or to conduct survey mapping work), the CPR will be retrieved and potentially redeployed, following suitable protocols to indicate the start and end of each deployment. The CPR sampling will occur in conjunction with measurements of atmospheric halocarbons and DMS. Establishing the plankton community composition will be advantageous to understanding what plankton species are associated with high atmospheric concentrations.

Voyage legs potentially suitable for CPR deployments include:

1. Fraser Island (post-CTD 1) to Swain Reefs (pre-Swain slide survey). Distance: 200 nm.
2. Swain Reefs (post-CTD 2) to central GBR (pre-CTD 3). Distance: 100 nm.
3. Central GBR (post-CTD 3) to northern GBR (pre-CTD 4). Distance: 200 nm.
4. Northern GBR (post-Stapleton canyons survey) to Cape York (pre-CTD 5). Distance: 100 nm.
5. Arafura Sea (post-Torres Strait exit) to Wessel Marine Park (pre-Wessel Island survey). Distance: 300 nm.
6. Wessel Island (post-Wessel Island survey) to Bathurst Island (pre-arrival in Darwin). Distance: 400 nm.

CSIRO Educator on Board program (CSIRO MNF)

CSIRO Educator on Board is a professional development program for Australian STEM (science, technology, engineering and mathematics) school teachers which aims to support teacher professional development and provide students with a window on the real world application of STEM. Educator on Board puts teachers on voyages to assist with scientific operations and share their on-board experience with students across Australia through live ship-to-shore video broadcasts. Teachers will also develop curriculum-linked resources based on the ship and underway science to create a pool of lessons to share in schools across Australia. Two teachers will be joining this voyage as part of the Educator on Board program, and will be encouraged to assist with science operations where possible, in consultation with the Principal Investigators and MNF onboard liaison.

BGC-Argo float deployment (Dr Tom Trull, CSIRO)

Biogeochemical-Argo (BGC-Argo) is the extension of the Argo array of profiling floats to include floats that are equipped with biogeochemical sensors for pH, oxygen, nitrate, chlorophyll, suspended particles, and downwelling irradiance. These newly developed sensors now allow profiling floats to also observe biogeochemical properties with sufficient accuracy for climate studies. This extension of Argo will enable an observing system that can determine the seasonal to decadal-scale variability in biological productivity, the supply of essential plant nutrients from deep waters to the sunlit surface layer, ocean acidification, hypoxia, and ocean uptake of CO_2. Biogeochemical-Argo will drive a transformative shift in our ability to observe and predict the effects of climate change on ocean metabolism, carbon uptake, and living marine resource management.

The Australian contribution to global Biogeochemical-Argo is coordinated through the BGC-Argo sub-facility component of Argo-Australia.

We will use this voyage to deploy 2x BGC-Argo floats at Dirk Erler's (Supplementary Project 2) CTD site #1. In addition, samples will be collected from the CTD Niskin bottles in order to calibrate the float sensors: including salinity, oxygen and nitrate by the MNF Hydrochemistry team, and TCO2, Alkalinity, POC (particulate organic carbon) and Pigments (chlorophyll and other pigments) by CSIRO Oceans & Atmosphere laboratories. Deployment of the floats will be managed by the MNF in conjunction with the deck crew. CTD samples will be managed by PI Erler and the onboard Hydrochemistry team.

Results

Supplementary Project 1: Deep seascapes of the Great Barrier Reef: Uncovering submarine canyons and landslides (Beaman)

Swain slide

The Swain slide is so named because it lies opposite the Swain Reefs and was discovered after several multibeam surveys transited across the lower slope of the Swain Reefs and over the Marion Plateau (Figure 2). The RV *Southern Surveyor* mapped the headscarp at the Swain Reefs in 2013, revealing a scarp width of approximately 10 km along the lower slope. A transit across the Marion Plateau by the RV *Sonne* in 2017 detected a rough patch of seafloor at the distal end of a debris field about 13 km to seaward of the headscarp. During this voyage, we approached the survey with a ship track that matched the RV *Sonne* data coverage and worked progressively landward parallel to contours.

Depths at the seaward extent of the survey were around 358 m, rising gently to around 320 m depth at the completion of the ~7 hour survey. The slide boundaries were much greater than had been anticipated based upon what had already been surveyed. At the distal end of the slide, the width was ~11 km, while the width at the proximal end of the slide (i.e. closer to the headscarp) was ~13 km wide. The longer time needed to find the edges of this much wider slide precluded completing the survey during this voyage, and so will require another survey to fully survey the slide. The headscarp was a farther 6 km away from the landward limit of the surveyed area. However, the survey coverage conducted was 100% and revealed much detail in the slide morphology.

The southern part of the slide is a mass of several large >2 km intact blocks, or rafts of seabed material about 20 m thick. These large blocks lie at distal end of the debris field and are surrounded by disaggregated smaller debris blocks with a distinct compression fabric, presumably where the larger blocks have pushed the smaller blocks together while travelling downslope. To landward, i.e. more proximal to the headscarp, are numerous (100+) medium-sized <1 km debris blocks. These medium-sized blocks are also around 20 m thick. The seafloor appears excavated beneath this large debris field, so the various larger rafts and smaller blocks are likely the remains of flat seafloor pushed down from close by before coming to rest inside the survey area.

The northern part of the slide mass does not have such an obvious debris field and the seafloor appears relatively smooth, however, sub-bottom profiles clearly show slide material extending as a thinning sheet from around 20 m thickness to pinch out at the slide edge. The original seafloor at this northern slide edge is slightly pushed down under the slide sheet, i.e. the weight of the slide mass appears to have pushed down the original seafloor. So, in contrast to the southern part of the slide, the original seafloor under this northern part of the slide is not excavated. The picture emerges of a sudden slide event resulting in a debris field of disaggregated blocks and large intact rafts of seafloor, while a debris fan of finer material has spread northwards over the original seafloor.

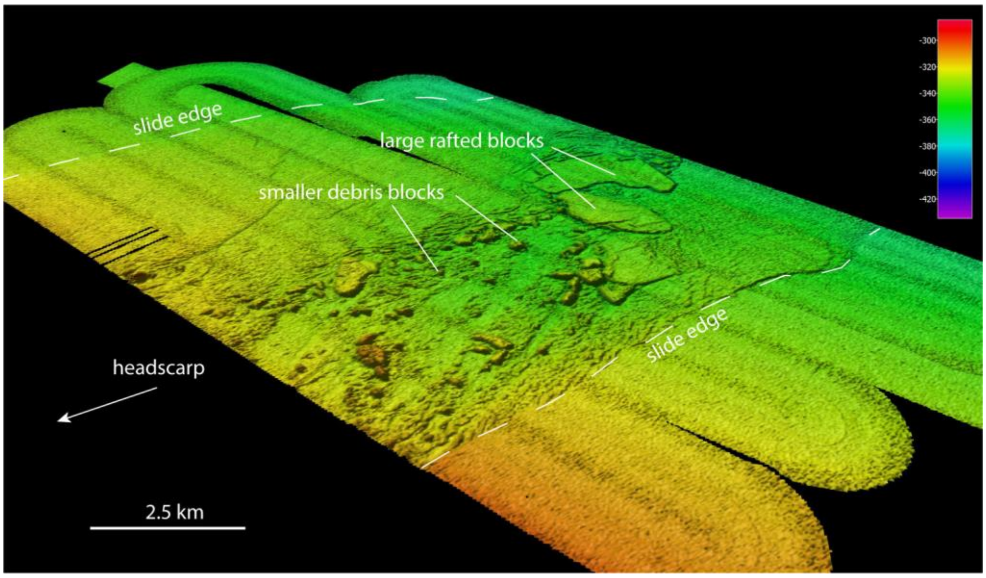

Figure 2. Northerly 3D view of the Swain slide. The headscarp lies a farther ~6 km towards the Swain Reef.

Bowl slide

The Bowl slide is named because it lies to seaward of the Bowl Reef on the central GBR shelf (Figure 3). Originally discovered in 2017 by the RV *Southern Surveyor*, there have been at least three more passes by various vessels mapping the farther extent of the slide to try and locate its full run out extent. In this voyage, we matched the transit against previous RV *Investigator* IN2016_V05 voyage multibeam data with a single pass to seaward. Swath width was about 4 km wide with the EM122 multibeam system. Depths at the southeast side of the debris field were ~980 m, becoming deeper towards the northwest across the field to ~1030 m. The debris field profile has a slight bow shape with the higher part of the field in the centre at ~970 m.

The addition of this new data shows this debris field continues extending seaward across the Queensland Trough to around 24 km distance from the headscarp on the upper slope. The width across the widest extent of the debris field is now mapped at 26 km wide, with still more of the debris field left to map to locate the further-most extent of this large landslide. The sub-bottom profiler data clearly shows small numerous debris blocks extending right across the slide area, which is dissimilar to the previous Swain slide, which shows a confined area of larger block debris. The Bowl slide also does not show a clear pre-slide seafloor in the sub-bottom data, indicating that the slide debris is thicker than shown at the Swain slide.

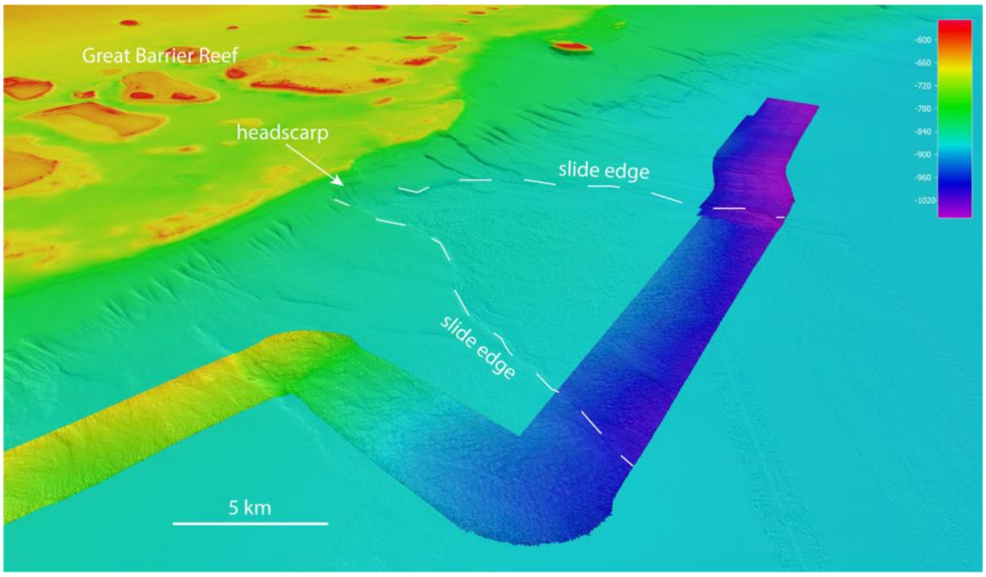

Figure 3. Westerly 3D view of the Bowl slide, showing the new multibeam data extending farther the slide debris field to ~30 km from the headscarp on the upper slope.

Stapleton canyons

The Stapleton canyons lie opposite the Stapleton Reef near Princess Charlotte Bay, Cape York (Figure 4). Earlier RV *Sonne* multibeam data from a transit across the lower slope in 2017 revealed the toe of canyons where they flattened into the adjacent deep Queensland Trough. A RV *Southern Surveyor* voyage in 2013 following the reef edge along the upper slope also revealed the heads of numerous canyons. This voyage aimed to fill in the gaps between these two surveys and reveal the full detail of the canyons across the entire slope. The new mapping data revealed an incredibly complex canyon system stretching right along the ~80 km distance of the slope surveyed, and extending out ~16 km away from the shelf-edge into the Queensland Trough

The shoalest depth was ~300 m, stretching down to ~2400 m depth in the Queensland Trough. The area was roughly bowl-shaped, following the slight curve of the shelf-edge. Over 29 main trunk canyons were mapped over that 80 km distance, while hundreds of smaller gullies were found on the flanks of these larger canyons. The longest canyon, from the landward-most survey area to the toe of canyon was around 11 km in distance. If adding the previously upper slope distance, then these canyons may extend ~16 km out from the shelf-edge, with heads of canyons starting in 200 m and dropping to ~2400 m depth, a depth range of ~2200 m.

These canyons all have remarkably sharp interfluves separating one canyon from the next, where erosion from adjacent canyons has completely eaten away at any flat continental slope, i.e. no flat continental slope remains. At several canyons in the northwestern side of the survey area, precipitous vertical walls appear in the canyon exes around 1300 m dropping to ~1900 m depth. These dramatic drops in canyon floor depths do not appear to be the result of landslides within the axes, as has been seen in the Ribbon slide to the south which is the result of a landslide at the base of these canyons. More mapping work is required to fully map the entire slope extent off Cape York to see whether the morphology of the canyons continues with the complexity shown in this voyage.

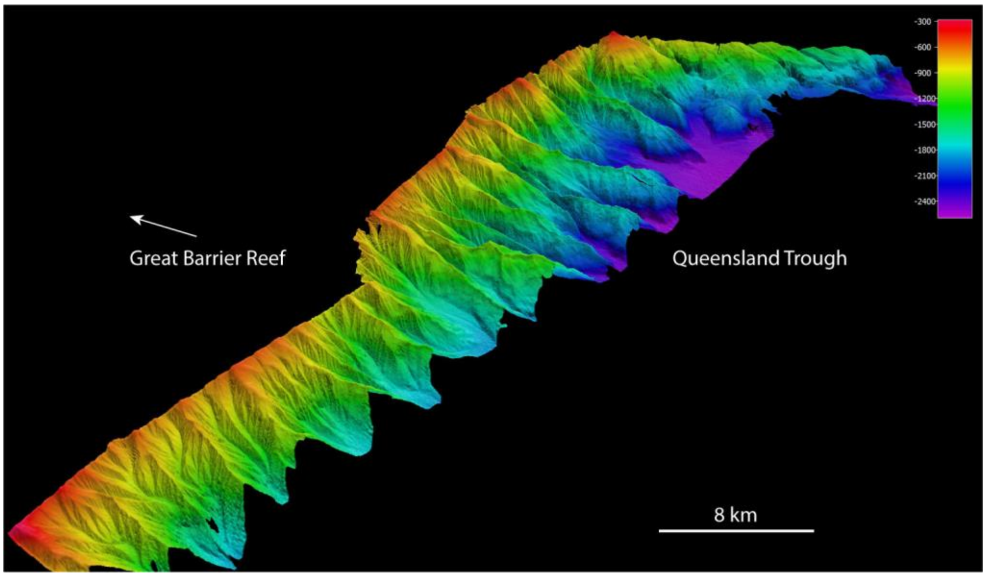

Figure 4. Westerly 3D view of the Stapleton canyons extending over a depth range of ~300 to 2400 m.

<u>Supplementary Project 2: First measurements of nitrate isotopic composition in the Coral Sea (Erler)</u>

Samples from throughout the water column were collected at four sites along the edge of the continental shelf between Fraser Island and Cooktown. Water samples were collected up to 2000 m of depth. Samples were collected for nitrogen isotope analysis of all nitrogen species including dissolved forms, organic forms, particulate forms, and gaseous forms. Once the data has been collated it will provide a two-dimensional depth profile of nitrogen cycling along the continental shelf. Unfortunately, one of the sites could not be sampled due to time constraints associated with a strong southward flowing current. However, two additional CTD casts were completed, enabling collection of seawater samples from a deep trough in the Wessel Marine Park, which appears to be a unique feature in an otherwise uniform seascape.

The analysis of collected samples is ongoing and final results are not expected until early 2020. Overall, the sample collection was highly successful. In addition to the Coral Sea sampling, opportunistic water sampling in the Wessel Marine Park has uncovered a unique filter feeding community that appears to be associated with a deep trough containing high concentrations of nutrients.

<u>Supplementary Project 3: Spatial and temporal variability in the distribution and abundance of seabirds (Woehler)</u>

Almost 3000 birds from 40 taxa were recorded during the survey. Approximately 12-13 hours of observations were made each day, comprising transits and stations. Observations commenced at sunrise and continued to sunset, depending on light conditions. In addition, records of marine mammals (cetaceans and seals) were also undertaken. All survey data will be submitted to GBIF in 2020 after data checking has been completed.

Supplementary Project 4: ORCA: Using the *Investigator* radar as a moving reference for the Australian operational radar network (Protat)

During this voyage, good ground clutter data was collected near the following radars: Brisbane (Mt Stapylton), Gympie, Townsville, Cairns and Darwin. This dataset will provide us with a unique opportunity to evaluate the quality of our operational radar calibration monitoring tools. It is too early to provide more inputs to this report at this stage as the analysis of radar data will only commence in January 2020 (Protat involved in IN2019_V06 and IN2019_T03).

Supplementary Project 5: Environmental baselines for Wessel Marine Park, northern Australia (Przeslawski)

The Wessel Marine Park project acquired multibeam data adjacent to that previously collected in 2005, as well as concurrent sub-bottom profile data. We also mapped a small grid to the south of this area over a possible raised geomorphic feature as indicated on the hydrographic chart. Four 1500 m video transects were undertaken across a range of geomorphic features and depth gradients, with the exception of CAM02, which was aborted after 600 m due to concerns the camera was at risk of collision due to low visibility and rocky outcrops. Two CTD casts were made, one at the deepest part of the study area and one at consistent shelf depths for the area. In addition, seabirds were monitored throughout the Wessel Marine Park as part of Supplementary Project 3 during this survey.

Full mapping and SBP profiles of the hole feature revealed four geological classes: basement rock in the southeast corner, in-filled paleochannels in the south, shifting bedforms at the southern end of the channel, and scree slope at the cliff edge. The rest of the surrounding area in the Wessel Marine Park is likely to be marine sediment plains. The CTD casts showed rather abruptly reduced oxygen and temperature starting at 60 m and extending into the deep hole.

The benthic environment in the study area was highly turbid with strong currents, making identification of individual animals difficult. Nonetheless, it was clear that suspension feeders including fan sponges (e.g. *Ianthella* spp.), sea fans (e.g. *Mopsella* spp.), and barrel sponges (e.g. *Xestospongia* spp.) were locally abundant on the edge and rocky slope of the hole. These sponge and octocoral gardens provided habitat for other animals such as crinoids and fish. The bottom of the hole showed scattered fish, as well as a highly localised dense population of brittle stars. In contrast the flat shelf around the hole feature supported only scattered small epifauna such as hydroids, ascidians, and sponges.

The poor quality of the towed imagery highlighted the challenges of monitoring our northern marine parks. Although we were able to identify broad habitat and community types, the turbidity of the region precludes identification of animals at anything other than the coarsest resolution. Future research in the area should explore alternative methods, such as acoustic cameras, as well as different lighting systems and orientations of towed systems deployed over varying tidal conditions.

Piggyback Projects

Trichodesmium sampling (Hawker)

Trichodesmium samples for culturing and filters for genetic analysis were collected at six existing CTD stations during the voyage. Four of these stations were located along the Great Barrier Reef margin, and two in the Arafura Sea, near the Wessel Marine Park (see Figure 5). *Trichodesmium* slicks were visible upon the transit out of Brisbane and for much of the transit across the Gulf of Carpentaria but were not visible for the remainder of the transit. CTD station #5 and #6 were conducted in areas with extensive visible slicks.

Several volunteers were actively involved in the sampling, including the two Educators on Board, Royal Australian Navy personnel and the onboard Parks Australia representative. Samples have been received by the Australian National Algae Culture Collection in Hobart, and culturing and analyses are currently underway.

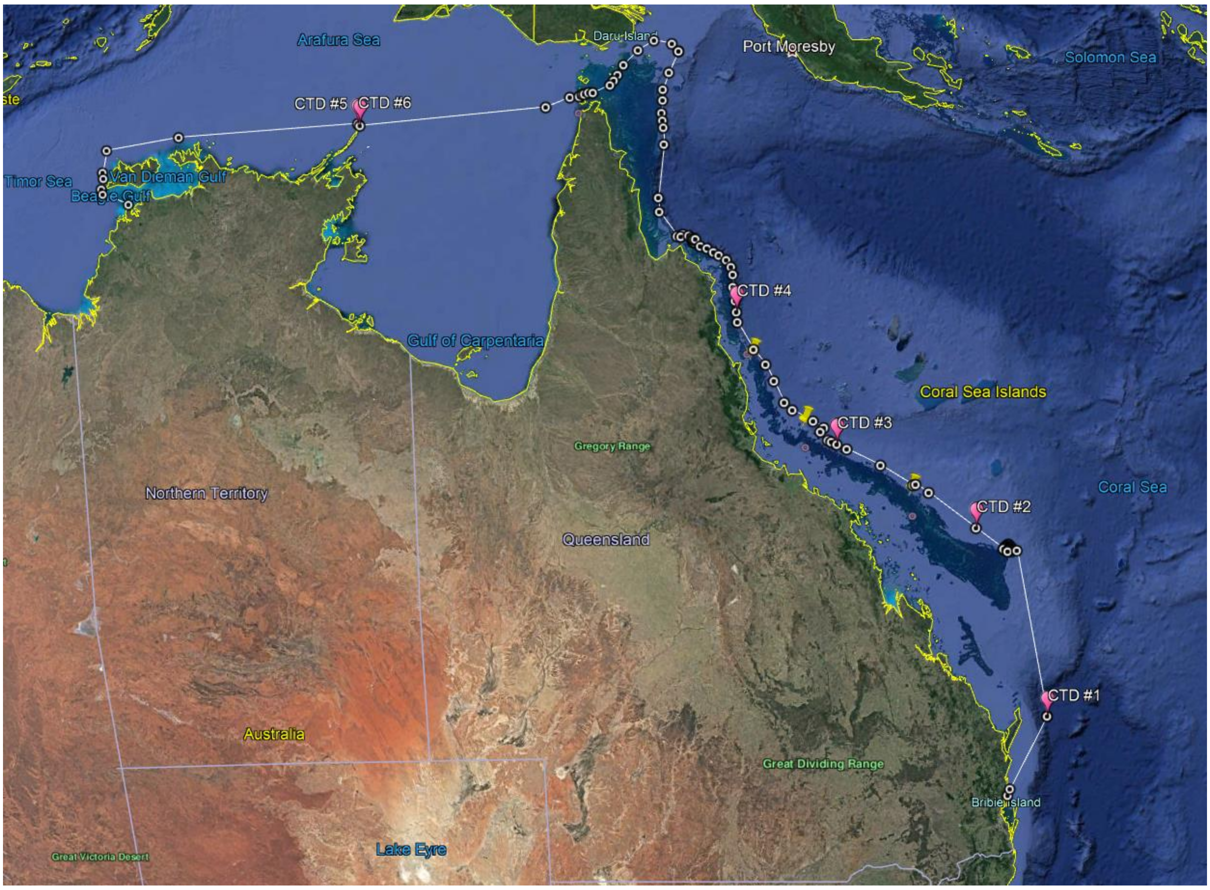

Figure 5: CTD stations during IN2019_T02 transit voyage. Culture and genetic samples for *Trichodesmium* were collected at each of these six CTD stations.

<u>AIR-BOX integration and calibration (Schofield)</u>

The integration and calibration of the AIR-BOX (a containerised laboratory which houses aerosol atmospheric monitoring instruments), guest instruments in the aerosol laboratory and air chemistry laboratories, as well as optical instruments located on deck 5, occurred during this voyage. This was in preparation for the following voyage IN2019_V06, during which the AIR-BOX will be utilised in conjunction with RV *Investigator*'s aerosol laboratory and air chemistry laboratory to continuously collect comprehensive atmospheric chemistry and aerosol measurements.

PI Schofield coordinated with the AIR-BOX consortium to conduct atmospheric biogenic air measurements, aerosol composition, aerosol profile and oxidative capacity measurements to understand the emissions and processing of sulphur and halocarbons from the ocean in this region.

Trace-gas and aerosol observations near the Great Barrier Reef were made continuously throughout this transit voyage.

Our team also contributed to the Continuous Plankton Recorder (CPR) sampling in conjunction with the AIR-BOX measurements. Three CPR cassettes were deployed during this voyage, across a total of six CPR tows. These cassettes remained onboard the vessel, to be sent back to Hobart upon the arrival of the vessel into Fremantle at the end of IN2019_T03.

CSIRO Educator on Board program (CSIRO MNF)

The two Educators on Board were actively involved in a range of voyage activities, particularly the *Trichodesmium* sampling and the seabird and marine mammal observation work. Throughout the voyage, the two Educators on Board conducted six highly successful live video crosses to shore-based classrooms. Both teachers were actively involved in assisting with the Public Open Day upon the arrival of the ship in Darwin, acting as tour guides for several school groups and the general public. Both teachers have commenced the development and classroom testing of their curriculum-aligned teaching resources based on the voyage activities.

BGC-Argo float deployment (Dr Tom Trull, CSIRO)

During this voyage, 2x BGC-Argo floats were deployed at Dirk Erler's (Supplementary Project 2) CTD site #1. In addition, samples were collected from the CTD Niskin bottles in order to calibrate the float sensors: including salinity, oxygen and nitrate by the MNF Hydrochemistry team, and TCO2, Alkalinity, POC (particulate organic carbon) and Pigments (chlorophyll and other pigments) by CSIRO Oceans & Atmosphere laboratories. Deployment of the floats was managed by the MNF in conjunction with the deck crew. CTD samples were managed by PI Erler and the onboard Hydrochemistry team.

Deployment of the two BGC-Argo floats was achieved very successfully. They had initially been intended for deployment at the IMOS East Australian Current (EAC) Moored Array during IN2019_V05, but a manufacturer recall of the satellite GPS instruments that track their positions caused a delay in their delivery. The effort by MNF, ASP and the IN2019_T02 science team to achieve their deployment is much appreciated. The floats were launched with an initial mission to profile daily to 1000 m depth, and this mission was maintained as they transited rapidly southward in the core of the EAC jet and through the Moored Array. This was a very satisfying outcome because it means that calibration samples collected during both voyages (IN2019_V05 and IN2019_T02) will enable comparison with the profiling float sensors. The floats have now been placed in the standard Argo global array mission of parking at 1000 m and then doing profiles from 2000 m to the surface every 10 days. Both floats should provide observations from the Tasman Sea for the next several years.

Float 590441 (grey line in Figure 6) is traveling slightly faster than float 590442 (red line in Figure 6), as shown in their trajectories from the first 14 days below.

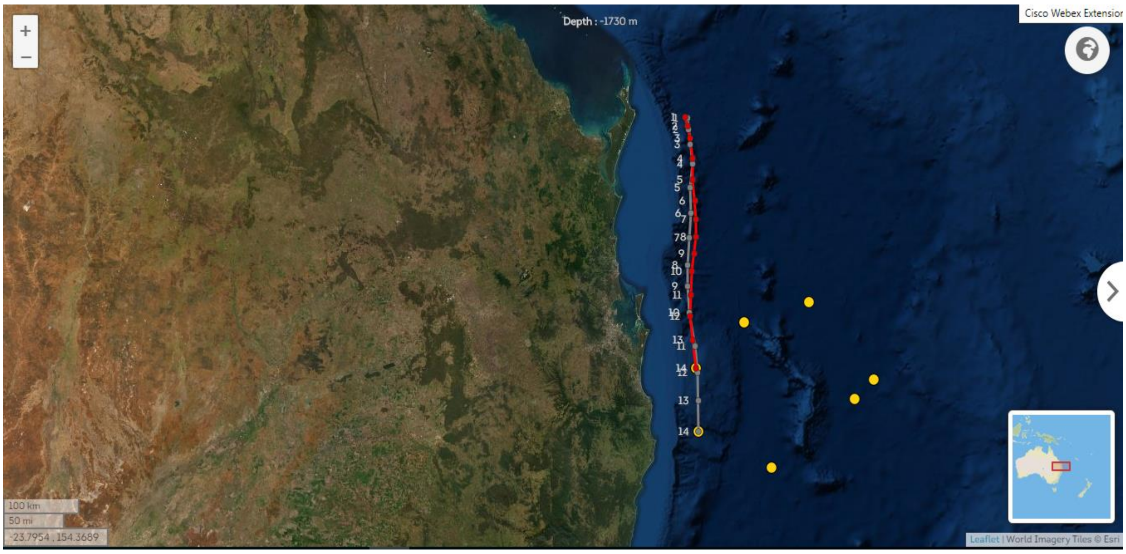

Figure 6: Trajectories of the two new BGC-Argo floats launched during IN2019_T02, showing their daily profile locations as they are swept southward in the core of the East Australian Current. The yellow dots show most recent profiles from core-Argo floats with only temperature and salinity sensors.

The first two weeks of daily profiles reveal the cooling and increasing salinity of the EAC jet as it travels southwards (see Figure 7). The surface waters are nitrate-depleted but overlay older nitrate-rich and oxygen-depleted waters. The classical sub-surface 'deep chlorophyll maximum' is clearly confirmed, but importantly the particle backscatter sensor reveals that this is primarily just an enrichment in chlorophyll levels with the phytoplankton as they attempt to balance the need for nitrate from below with the waning light levels from above, and is not represented by significant increases in biomass. The strong decrease in pH below the surface reveals the complex interplay that accompanies exchanges with this layer; it provides nitrate to fuel production, but this is accompanied by the stress of ocean acidity. Importantly, all these sensor signals must now go through rigorous quality control using the calibration samples collected from the CTD Niskin casts during the voyage, which are currently being analysed in the Hobart laboratories.

All the BGC-Argo float data is delivered live to the mirrored Global Data Acquisition Centres in the USA and France, and can be accessed via links from the Argo Australia Facility on the IMOS website (www.imos.org.au).

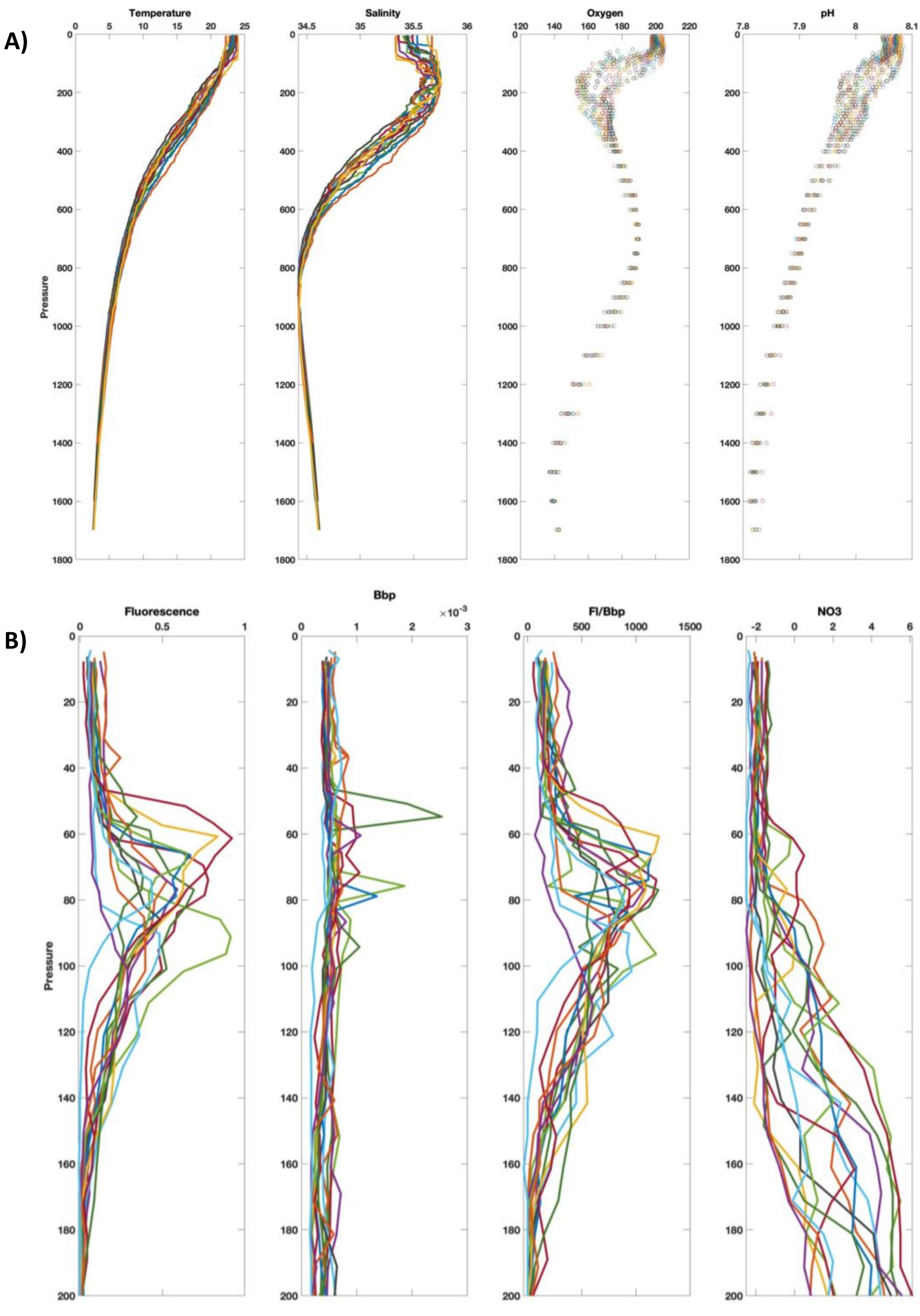

Figure 7: A) structure of the EAC jet in the top 1000 m as revealed by Float 5905441 over the first two weeks; B) near-surface biological distributions and their relationship to the depth of nitrate availability, known as the nitricline.

Voyage Narrative

Friday 4th October 2019

Wind 3 kn from 254°. Sea state 1. Nil swell.

0500 in position 27° 24.4'S; 153° 08.7'E berthed at the Wagners Wharf, Port of Brisbane.

At 0500 we left Wagners Wharf in the Brisbane River and headed into Moreton Bay with the pilot. The EM710 multibeam system commenced logging. At 0900 we exited Moreton Bay where the pilot disembarked and we then headed north-east onto the Fraser Shelf for the transit to CTD Site 1 off Fraser Island. The seafloor was mostly dynamic bedforms with sandsheets and dunes. We exited off the shelf around 1700, heading obliquely across the upper slope. The EM122 system was started for the first time with good quality data being collected from a depth of 150 m. The EM710 was turned off when depths of ~800 m was reached. Through the evening we mapped the heads of the canyons draining off the Fraser Shelf. At 2030 we arrived at the first CTD Site 1 and commenced a CTD dip to 2000 m. The CTD sampling continued through to 2330, after which the two BGC-Argo floats were deployed and we then continued on with the transit.

Saturday 5th October 2019

Wind 7 kn from 100°. Sea state 2. Low swell.

0600 in position 23° 40.3'S; 153° 41.7'E over the Fraser Canyon, Tasman Sea.

After completing the CTD Site 1, we headed northward toward the Swain Reefs, passing over the large Fraser Canyon reaching a maximum depth of ~4080 m in the axis of the canyon. At 0100 we crossed into the GBR Marine Park. Depths gradually shallowed towards ~300 m on the South Marion Plateau. The EM710 was turned on showing a relatively flat seafloor with generally consistent backscatter reflectance. At 1000 we conducted a sound velocity profile to overcome any issues around the East Australian Current (EAC) eddy effects on the sound velocity (SV) for the multibeam systems. At 2300 we arrived at the start of the Swain slide survey area and commenced surveying with both the EM122 and EM710 systems.

Sunday 6th October 2019

Wind 7 kn from 090°. Sea state 2. Low swell.

0600 in position 20° 56.5'S; 152° 36.4'E conducting the Swain slide survey.

Through the early morning we surveyed across the Swain slide area, working our way landwards toward the reef. The slide is far bigger than expected, at least twice the size of the disturbed area we initially mapped in the 2017 RV *Sonne* voyage. There is a central mass area with coherent blocks and slabs, at least 20 m thick, all lying within a larger area of the debris with compression ridges at the seabed surface. By 0600 we had completed the survey about halfway toward the edge of the Swain Reefs, then departed for the transit towards CTD Site 2. We arrived at Site 2 around 0900 for a CTD dip over an hour long. Unfortunately, we lost the sound velocity probe from the CTD after it detached from the frame. We continued along the upper slope with a seafloor relatively smooth in depths around 300 m. Through the day we continued tracking northwest across the front of the Swain Reefs.

Monday 7th October 2019

Wind 8.3 kn from 101°. Sea state 2. Low swell.

0600 in position 18° 52.6’S; 148° 43.8’E transiting across the upper slope near Dingo Reef.

We continued along the GBR upper slope in depths of around 300 m. The seafloor was relatively flat with little change in geomorphic relief. All multibeam systems and sub-bottom profiler were working OK. We arrived at CTD Site 3 in 430 m depth at 0930 and conducted a one-hour CTD dip. From 1130 we then continued northwest towards the Bowl slide survey area offshore from Townsville. At 1400 we arrived at the Bowl slide area and ran adjacent to a previously surveyed multibeam line to extend farther our understanding of the full runout of the slide debris field, over 30 km from the headscarp. We completed the Bowl slide survey around 1600 and continued surveying along the upper slope towards Cairns, crossing the first of many canyons north of Palm Passage.

Tuesday 8th October 2019

Wind 10 kn from 128°. Sea state 2. Low swell.

0600 in position 16° 25.7’S; 146° 11.4’E transiting across the upper slope near Norman Reef.

Through the night we transited along the upper slope between Townsville and Cairns. Submarine canyons became more prominent and closer together as we sailed northward. At 0400 we were offshore of Cairns with only the EM122 multibeam system used through this area. By 0900 we were off Agincourt Reef and could clearly see the Ribbon Reefs and dive pontoons. The Ribbon Canyons now appeared with their far more dramatic relief compared to those Noggin-style canyons to the south. The track followed was selected to help fill in gaps within the previous multibeam coverage.

Wednesday 9th October 2019

Wind 13 kn from 116°. Sea state 2. Low swell.

0600 in position 13° 40.6’S; 144° 47.5’E transiting north across the Osprey Embayment.

From around midnight we commenced mapping the Stapleton canyons, named because of their proximity to the Stapleton Reef near Cape York. The survey area was bowl-shaped with canyons draining from the shelf edge into the Osprey Embayment at around 2400 m depth. Through the early morning the mapping revealed a highly complex canyon system with very sharp ridges separating adjacent canyons axes. By 0415 we had completed surveying this canyon area and commenced the transit northward toward the Torres Strait. The vessel’s drop keels were raised to increase speed and we continued EM122 multibeam mapping, crossing the Bligh Canyon at midday in depths of ~3200 m. At 2200 we sailed between Ashmore Reef and Boot Reef.

Thursday 10th October 2019

Wind 13 kn from 105°. Sea state 1. No swell.

0600 in position 09° 22.8’S; 143° 36.4’E transiting through the Torres Strait.

At 0200 we transited onto the Gulf of Papua shelf and the shallower waters of the north-eastern Torres Strait. When depths reached ~100 m, the EM122 multibeam system was turned off and the EM710 turned on. The SBP120 system continued recording data. We continued southwest across the

Torres Strait, picking the pilot up around 0800 to guide the ship through the numerous shoals and islands dotting the Torres Strait. At 1600 we exited the Torres Strait through the Prince of Wales Channel and continued westerly into the Gulf of Carpentaria.

Friday 11th October 2019

Wind 11 kn from 061°. Sea state 2. Nil swell.

0600 in position 10° 49.8'S; 138° 53.7'E in the northern Gulf of Carpentaria.

We continued tracking westerly with good speed across the northern Gulf of Carpentaria, heading toward the next study area at the tip of the Wessel Islands. The seafloor was relatively flat with little geomorphic relief. The sub-bottom profiler revealed a prominent reflector below the marine sediments, likely to be the Pleistocene surface. Toward the approach to the Wessel Islands, pockmarks appeared in the seafloor typically as clusters but also as individual pockmarks several metres wide and about a metre deep. We arrived at the Wessel Marine Park site at 1600 and commenced an EM710 multibeam survey in ~50 m, remapping a strip of the 2005 bathy area to look at bedform stability and completing approximately 16 km^2 of new mapping to the west of the 2005 grid. This mapping showed the extent of a feature consisting of a prominent tidally scoured hole at ~100 m, with interesting boulder fields and rock platforms. The seabed in the hole was dominantly sediment overlying a hard substrate, while the inner rim of the hole was hard rock. We mapped an area south of the study area marked on the hydrographic charts as a slightly raised (49 m) feature from the surrounding seabed (62 m). This ended up being an extremely flat seabed, revealing an error in the charts. We continued the EM710 and sub-bottom profiler survey through the evening to build up a 3D picture before commencing towed imagery operations around and through the hole feature.

Saturday 12th October 2019

Wind 4 kn from 068°. Sea state 1. Nil swell.

0600 in position 10° 56.2'S; 136° 45.0'E at the Wessel Marine Park survey.

From around midnight we stopped the EM710 multibeam survey and commenced a series of deep tow video transects across prominent geomorphic features. The first camera tow confirmed high turbidity and strong currents, and the operator aborted the transect 600 m in. Nonetheless, we could see obvious sponge and octocoral gardens. The remaining three video transects were better quality but still typically turbid. It seems obvious that the rim of the hole feature and the rugged slope down into it is a 'sweet spot' for benthic communities, showing higher densities and diversity of sessile invertebrates in this area than the surrounding hole and shelf. Benthic cover increased across the flat platform and closer to the edge of the hole, with many large sponges observed. The steeper sides of the hole had the highest benthic cover with numerous boulders covered in colourful sponges. The deepest part of the hole in ~100 m was very muddy where benthos became sparser. Clusters of brittlestars were observed in the deepest part of the hole. The video transects were completed around 0500. We then conducted two CTD casts, one in the hole feature and another on the shelf. The former confirmed stratification in the hole feature, with temperature, oxygen, and salinity variation at 60 m. This was followed by some additional EM710 multibeam lines to build up the area surveyed. At 0800 we completed the Wessel Marine Park survey and commenced the transit toward Darwin.

Sunday 13th October 2019

Wind 5 kn from 095°. Sea state 1. Nil swell.

0600 in position 10° 48.3’S; 132° 34.8’E in the Arafura Sea.

Through the night we continued our westerly transit toward Darwin. In the early morning we crossed through the Arafura Marine Park, collecting EM710 multibeam data in depths of ~60 m. Numerous pockmarks were observed, as well as infilled palaeo-channels. We crossed north of Cobourg Peninsula, again with numerous pockmarks observed in the bathymetry data. During the afternoon, we sailed north of Melville Island and Bathurst Island where pockmarks or pits became very dense in the relatively flat seafloor. Palaeo-channels were still very obvious in the sub-bottom profiles. At 1900 we rounded Bathurst Island and then headed southwards towards Darwin in ~60 m depth.

Monday 14th October 2019

Wind 2 kn from 070°. Sea state 1. Nil swell.

0600 in position 12° 18.7’S; 130° 38.9’E approaching Beagle Gulf

We continued EM710 mapping the western side of Bathurst Island and then into the Beagle Gulf, matching the EM710 data coverage against the previously surveyed RV *Sonne* SO256 multibeam data collected in 2017. At 0800 we picked up the pilot for the approach to Darwin Harbour. At 0900 we turned off the EM710 multibeam and SBP120 sub-bottom systems and tied up alongside in Darwin Harbour.

Summary

From an operational standpoint, the IN2019_T02 voyage from Brisbane to Darwin was a great success. The voyage was completed on time and achieved most of the field mapping objectives. We are confident that our post-voyage analyses of the marine geophysical data will enable us to achieve the scientific objectives to improve the bathymetric datasets available for the GBR continental slope and construct a comprehensive new inventory of the key landslides and canyons and their detailed geomorphic traits.

The data will also provide information at the regional-scale regarding the sedimentary processes and evolution of the margin, as a crucial first step toward understanding landslide susceptibility, tsunami hazard and improved risk assessments. We can also use the data to construct and validate numerical, basin-scale, stratigraphic forward models used to test sedimentary source-to-sink processes in this mixed siliciclastic-carbonate setting.

The new data will also be used as site survey data for a future International Ocean Discovery Program (IODP) Ancillary Project Letter (APL) proposal, with the aim to core the canyon deposits and recover coarse-grained, shallow-water carbonate sediments shed from the shelf, to better constrain the timing of the onset of the GBR.

The seawater collection component of the voyage was largely successful and collected water samples are now being processed for the various parameters. The data that will be generated from this voyage will be highly significant for a number of nutrient cycling related projects in the GBR. We expect that the collected data will be used for at least two publications. Given that these are the first measurements of nitrate isotopes in the Coral Sea, we expect that these publications will be well cited.

The OceanPOL radar operated 100% of the time during the experiment and collected ground clutter data collocated with several ground radars from the Australian radar network. This will provide us with a unique opportunity to evaluate the quality of our operational radar calibration monitoring tools. The only factor which limited our data collection ability during this voyage was the absence of any weather systems within range during the whole voyage.

The Wessel Marine Park project proved to be an excellent example of how repeated opportunistic data collection during transit surveys can build a knowledge base that can contribute to marine park management and engagement with local indigenous communities.

This study contributes to an understanding of the values of a northern marine park, including an inventory of communities and habitats as well as potential relationships to geomorphic data. This has national significance for the implementation of the northern marine park management plan, as well as informing future monitoring programs in northern Australia.

With the additional marine imagery collected from the Wessel Marine Park, the complete image library can be annotated to generate a quantitative dataset from which ecological analyses can be performed using environmental variables derived from bathymetry and backscatter data. Such analyses would reveal representative or unique communities and habitats and how these are spatially distributed relative to environmental variables.

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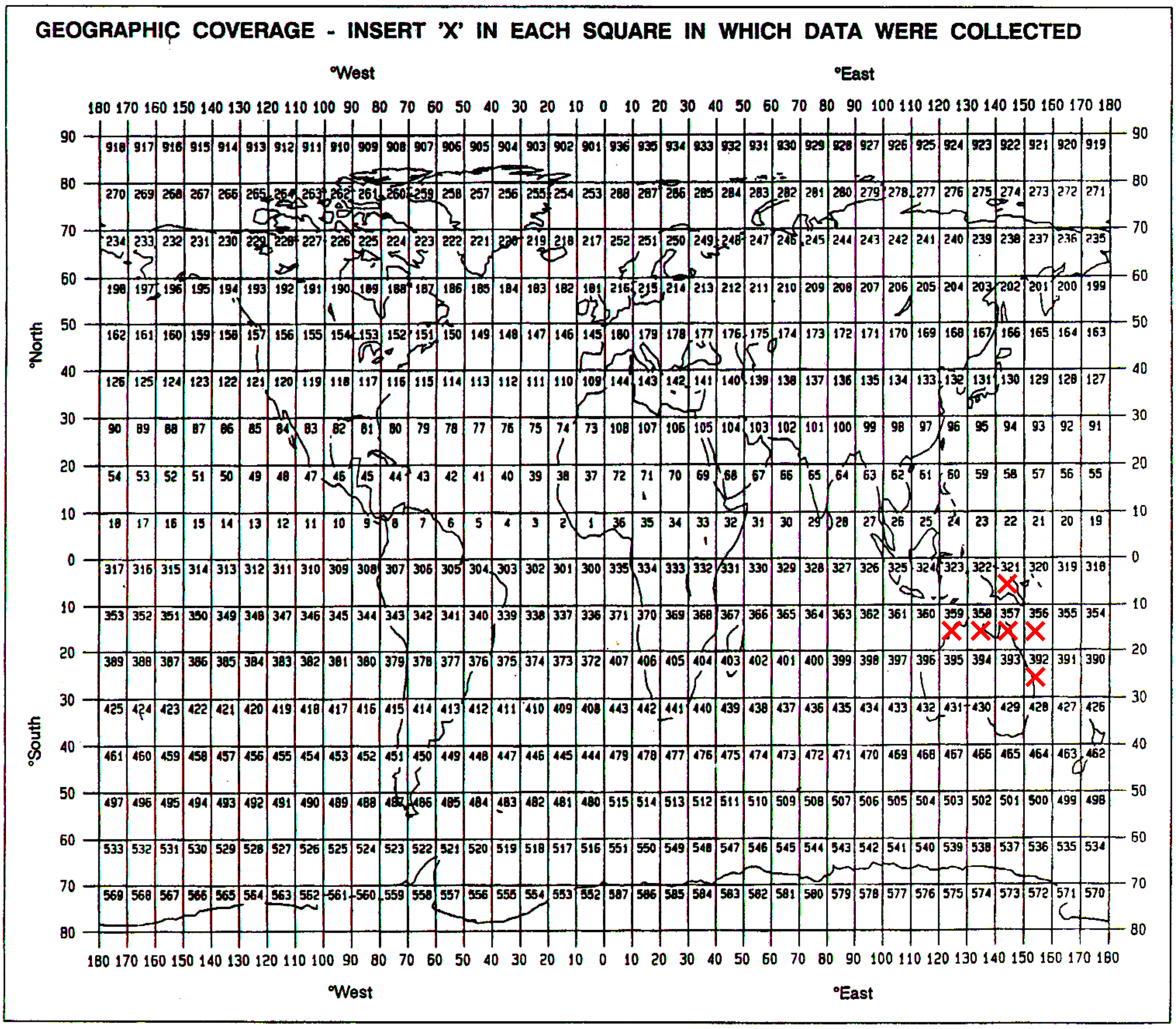
Marsden Squares



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		
	Trull	24	52.63	S	154	03.57	E	D05	BGC-Argo float #7770 deployed at PI Erler's CTD station #1.
	Trull	24	52.62	S	154	03.58	E	D05	BGC-Argo float #8357 deployed at PI Erler's CTD station #1.

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.
CTD	Erler	6	CTD casts	H-21, 22, 23, 24, 25, 26, 27, 32, 33, 75, 76	6 individual CTD casts were conducted with 10 depths sampled during each cast. Some parameters were measured onboard while others will be measured post-voyage.
Multibeam acoustics	Beaman, Przeslawski	3413.66	Km	G74	EM710 multibeam data collected during transit and site surveys.
Multibeam acoustics	Beaman, Przeslawksi	2468.26	Km	G74	EM122 multibeam data collected during the transit and site surveys.
SBP	Beaman, Przeslawski	~4800	Km	G75	SBP120 sub-bottom profiler data collected during the transit
Deep tow camera	Przeslawski	4	Tows	B18	Three 1500 m deep tow camera video transects were undertaken within Wessel Marine Park. One of the tows (CAM02) was aborted after 600 m due to very poor visibility and the presence of rocky outcrops, creating a collision risk.
Seabird observations	Woehler	28	Days	B25 + B26	Observations of seabirds and marine mammals during daylight hours. Almost 3000 individuals recorded from 40 taxa. All data are geo-referenced and will be lodged with GBIF in 2020 following processing and checking.
Weather radar	Protat	28	days	M90	6-minute resolution volumetric scans made of 14 successive elevations ranging from 0.5° to 32°, measuring radar reflectivity, Doppler velocity, spectral width, and polarimetric variables.
CTD	Trull	1	Station	H10	Additional Niskin bottle samples taken at PI Erler's CTD station #1 to calibrate BGC-Argo float sensors, including salinity, oxygen and nitrate by the MNF Hydrochemistry team, and TCO2, Alkalinity, POC (particulate organic carbon) and Pigments (chlorophyll and other pigments) by CSIRO Oceans & Atmosphere laboratories.
Plankton net	Hawker	6	Hauls	B07	Plankton net deployed by hand to collect *Trichodesmium* samples from the surface for isolation and culturing.
CTD	Hawker	6	Stations	B07	Surface CTD Niskin bottle samples collected for isolation and culturing of *Trichodesmium* and filtration for genetic analysis.

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.
CPR	Schofield		Km of tow length	B08 + B09 + B03 + B10 + B11	Six CPR deployments to sample plankton communities in conjunction with atmospheric measurements (to determine associations between plankton species and high concentrations of atmospheric halocarbons and DMS).
Atmospheric	Schofield	28	Days	M71	miniMPL Lidar continuous backscatter profiles of the atmosphere (30 second scans) – port to zenith. Will provide continuous aerosol and boundary layer height information.
Atmospheric	Schofield	28	Days	M71	MAXDOAS passive solar UV-Vis spectra at a number of angles out port side – port to zenith. Provides Ozone, NO2, HCHO, BrO, IO, O4 and aerosol boundary layer profiles.
Atmospheric	Schofield	28	Days	M71	Sea-state cameras – provide 3D images of the sea-state 20 mins every hour during daylight hours.
Atmospheric	Monty/ Schofield	28	Days	M90	Sonic anemometers – providing 10Hz 3D winds, humidity and temperatures on the aerosol foremast. Will provide eddy covariance sensible, latent, momentum and gas flux measurements.
Atmospheric	Alastair Williams/ Schofield	28	Days	M71	30 minute Radon observations within AIR-BOX.
Atmospheric	David Griffiths/ Schofield	28	Days	M71	Spectronus greenhouse gas observations CO2, CH4, N2O, CO and isotopes.
Atmospheric	Tony Morrison/ Schofield	28	Days	M71	Tekran 5 minute total gaseous mercury measurements.
Atmospheric	Damien Callahan/ Schofield	28	Days	M71	uDirac 10 minute halocarbon observations.
Atmospheric	Schofield	14	Days	M90	Meteorological station (Lufft WS800): temperature, pressure, RH, solar radiation, rain and 3D winds on deck 4 railing.
Atmospheric	Cravigan	15	Days	M71	VH-TDMA aerosol hygroscopicity.
Atmospheric	Cravigan	0	Days	M71	Aerosol Mass Spectrometer (AMS) Provides real time size and chemical mass composition (Organics, SO42-,

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.
					NO3–, NH4+, Cl–) of non-refractory sub-micron aerosol particles.
Atmospheric	Cravigan	28	Days	M71	Neutral cluster and Air Ion spectrometer (NAIS) Aerosol number and size particles: ~2 to 40nm, ions: 3.2 to 0.0013 $cm^2/V/s$, (equivalent size range: 0.8 to 40 nm).
Atmospheric	Cravigan	28	Days	M71	Scanning Mobility Particle Sizer SMPS – aerosol size distribution.

Curation Report

Item #	DESCRIPTION
1.	EM710 multibeam data held by R. Beaman, College of Science and Engineering, James Cook University
2.	EM122 multibeam data held by R. Beaman, College of Science and Engineering, James Cook University
3.	SBP120 sub-bottom profiler data held by R. Beaman, College of Science and Engineering, James Cook University
4.	Towed video data held by R. Przeslawski, Discovery and Engagement, Geoscience Australia
5.	CTD water samples held at Southern Cross University by Dirk Erler, Centre for Coastal Biogeochemistry
6.	Trichodesmium culture samples and filters for genetic analysis are currently held by the Australian National Algae Culture Collection at the CSIRO Hobart Laboratories.
7.	Additional CTD samples collected for calibration of BGC-Argo float sensors are currently held by the CSIRO Oceans & Atmosphere laboratories for further analyses.

Track Chart

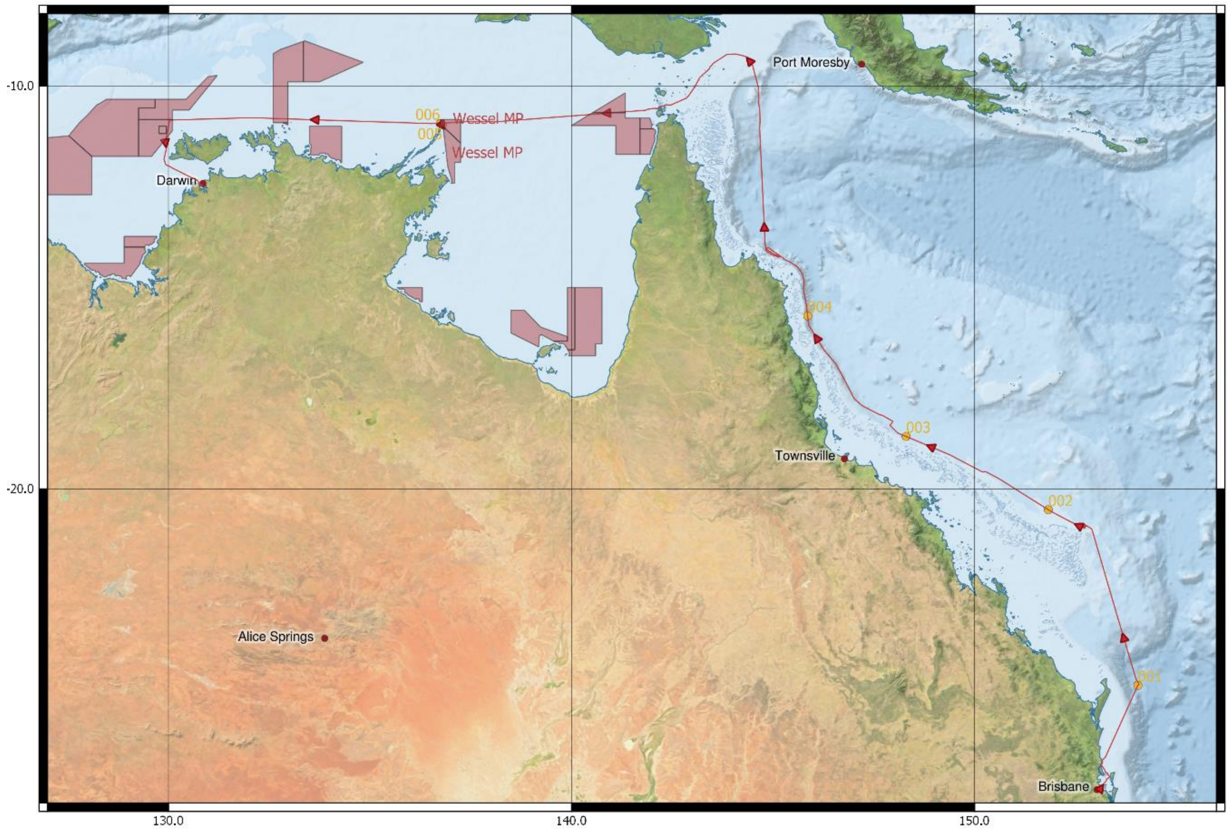


Figure 8: IN2019_T02 voyage track, with the six CTD stations shown in yellow.

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 – Photographs

Figure 9: *Trichodesmium* slicks visible along the transit across the Gulf of Carpentaria (Photo: Megan Dykman/CSIRO).

Figure 10: *Trichodesmium* slicks visible along the transit across the Gulf of Carpentaria (Photo: Kylie Jones/BirdLife Australia).

Figure 11: Preparation of CPR cassette by PI Robyn Schofield and Jason Monty (Photo: Cass Erbs/CSIRO).

Figure 12: Two Educators on Board (Chris La Rosa and Greta Creed) undertake a live video cross to onshore classrooms (Photo: Cass Erbs/CSIRO).

Figure 13: Deployment of the deep tow camera during the Wessel Marine Park survey (Photo: Cass Erbs/CSIRO).

Figure 14: A pod of bottlenose dolphins observed from the bow of the vessel (Photo: Eric Woehler/BirdLife Australia).

Figure 15: A brown booby (Photo: Eric Woehler/BirdLife Australia).

Figure 16: An osprey perched on the foremast (Photo: Kylie Jones/BirdLife Australia).

Figure 17: PI Dirk Erler sampling from the CTD (Photo: Cass Erbs/CSIRO).