RV *Investigator* Voyage Summary

Voyage #:	IN2016_V01		
Voyage title:	HEOBI – Heard Earth-Ocean-Biosphere Interactions		
Mobilisation:	Fremantle, Wednesday-Friday, 6-8 January 2016		
Depart:	Fremantle, 1330 Friday 8 January 2016		
Return:	Hobart, 0815 Saturday, 27 February 2016		
Demobilisation:	Hobart, Saturday, 27 February 2016		
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Objectives and brief narrative of voyage

Scientific objectives

Iron supply limits oceanic primary production in the Southern Ocean as well as elsewhere in the global ocean. We aim to test the hypothesis that hydrothermal activity driven by active submarine magmatism fertilises surface waters with iron, thereby enhancing biological productivity. Heard and McDonald islands on the Kerguelen Plateau are among the world's most active hotspot volcanoes, and are type examples sourced from a particular geochemical component in the Earth's mantle (enriched mantle 1, or EM1). Existing data indicate that fields of submarine volcanoes extend for several hundred kilometres away from the islands.

We will produce three-dimensional, high-resolution bathymetric, backscatter, and sub-seafloor maps of the seafloor surrounding the islands in near-real time. From this mapping and data from geotagged seals indicating locations of anomalously warm bottom water, together with deep tow camera imaging and TRIAXUS sensor data, we will identify candidate active submarine volcanoes and hydrothermal systems, and sample these volcanoes and their surrounding shallow sediments. In the water column over and downstream of these active volcanoes/hydrothermal systems, we will measure temperatures and obtain water samples for geochemical and biogeochemical analyses that will indicate the presence or absence of associated hydrothermalism and iron and other elemental enrichment. We will also sample the deep boundary current that impinges on the northeast flank of the Plateau, to investigate the generation of internal waves that enhance mixing of surface and subsurface waters, providing a mechanism to deliver iron enriched waters to the surface downstream of the volcanoes. If hydrothermally derived iron and other micronutrients are ascending to surface waters, we will compare our data to contemporaneous shipboard and satellite-derived estimates of phytoplankton productivity and biomass to test for positive temporal and spatial correlations.

Should it be proven that hydrothermally derived iron exerts controls on the dynamics of plankton blooms, this will be the first demonstration of linkages between dynamic solid Earth processes (magmatism) and major biological processes (oceanic primary production). Plankton blooms, in turn, affect the biogeochemical cycles of carbon, nitrogen, silicon, and sulphur, and ultimately influence the Earth's climate system. Our results could therefore open significant new avenues of research in the solid Earth-Earth's biosphere domain, including investigations of both past (e.g., oceanic anoxic events) and future (e.g., high atmospheric CO_2) extreme Earth environments.

Voyage objectives

Seafloor and subseafloor mapping/geophysical characterisation

Continuous mapping will be carried out using the multibeam systems, multi-frequency split-beam echosounders, sub-bottom profiler, gravimeter, and (on long transits between ports and the study area) magnetometer to characterise bathymetric features and identify those most likely to include volcanic or hydrothermal activity. Expendable bathythermograph (XBT) or conductivity-temperature-depth (CTD) data will be acquired at standard intervals for sound velocity corrections to the multibeam data. The data will be initially processed at sea to inform site selection for volcanic and hydrothermal sampling.

Nature of submarine volcanoes and hydrothermal systems

Dredges near fields of sea knolls have yielded volcanic rocks with ages as young as 30 Ka, suggesting that the features are recently active or active volcanoes. Data from geotagged seals suggest that some of the volcanoes have active hydrothermal systems. These prospective active submarine volcanic fields are up to 300 km from active subaerial hotspot volcanoes (Heard and McDonald Islands). The suspected broad temporal and spatial distribution of active volcanism on the Plateau will be used to test current mantle plume or lithospheric convection models.

We will characterise the spatial distribution, morphology, and geology of active submarine volcanoes and hydrothermal systems. Initial characterisation will be undertaken using multibeam and multi-frequency split-beam echosounder data; prospective active hydrothermal systems identified from these data will be imaged using the deep tow camera, and if active, we will sample the volcanic edifices hosting these systems by dredging/coring/sticky wax cores.

Detailed characterisation will involve sampling of:

- hydrothermal fluids and gases to illuminate the origin, nature, and chemistry of hydrothermal inputs to the ocean, and to determine the depths of volatile formation and release. Ideally, these fluids and gases will be sampled using gas tights.
- rocks from active volcanoes and near hydrothermal vents to reveal eruption type and process, geochemistry, and age. These rocks will be initially described on the ship and then archived for shore-based studies including petrology, geochemistry, and geochronology.
- sediment cores (multicorer, box corer, gravity and piston cores) on volcaniclastic aprons to evaluate the timing and geochemical evolution of active submarine volcanic fields. The multicorer will have a payload that includes a down-looking camera.

Detecting hydrothermal inputs to the ocean, and vertical water movements that deliver them to surface waters

Our strategy for identifying hydrothermal inputs to Central Kerguelen Plateau waters and for investigating vertical water movements that carry these inputs to surface waters includes the following:

- A full-depth CTD/lowered acoustic Doppler current profiler (LADCP)/trace metal rosette (TMR) transect from ocean basin waters, onto the base of the Plateau flank, and up the slope onto the crest of the Plateau will be conducted, repeating the KEOPS ‘B’ transect, capturing cross-shore gradients in water properties, and detecting the export of hydrothermal elements and minerals in the Deep Western Boundary Current (DWBC) that scours the eastern side of the Plateau.
- The vertical transport from interactions of the DWBC with topography, including internal waves, will be determined to evaluate its role in delivering enriched waters to the surface and supplying the high productivity seen in ocean color images northeast of the Plateau.
- This cross-slope transect will also contribute to a four-ship, multinational, simultaneous survey of the DWBC.
- A broad-scale survey over the plateau containing Heard Island and McDonald Islands will be conducted, including:
    - Multibeam mapping, multi-frequency split-beam echosounding, and sub-bottom profiling;
    - TRIAXUS tows to either 200 or 300 m as water depth allows, including additional sensors, Eh meter, nephelometer, transmissometer, and a miniaturized sampler (MINIMONE

provided by Kochi University, Japan) which will collect samples for measurements of possible hydrothermal waters (both on-board – O, Si, Fe, Mn – and in Hobart – Mg/Ca);
  - Shipboard ADCP observations to determine horizontal currents;
  - CTD/LADCP/TMR stations;
  - Bio-optical stations;
  - Drifter deployments to identify currents;
  - Oxidation Reduction Potential (ORP) sensors deployed on the TRIAXUS and the CTD;
  - Miniature Autonomous Plume Recorder (MAPR) for recording light-backscattering (for suspended particle concentrations), oxidation-reduction potential (ORP, for detecting the presence of reduced chemical species such as H_2S and Fe^{2+}), temperature, and pressure;
  - *In situ* pumps to characterise trace elements in particles;
  - The MNF particle backscatter sensor to allow particle fields such as those formed by hydrothermal vent 'smokers' and/or resuspended sediments to be localised.
- High-resolution model simulations, ~1 km spatial resolution.
- Deep tow camera to identify hydrothermal vents.

Using a combination of CTD, TMR, *in situ* particle (ISP) pumps, and sampling of the ship's trace-metal clean seawater supply, we will collect clean samples for shore-based analysis ($^3He/^4He$ anomalies, microscopic mineralogy, rare earth elements, macro-nutrients, Fe, Mn, dissolved and particulate elemental ratios, stable isotopes (e.g., iron), radiogenic isotopes (e.g., thorium), X-ray synchrotron mineralogy of particles, and other hydrothermal signatures). Dissolved Fe, Mn, H_2O_2, and Fe(II) will be determined at sea by flow injection analysis in samples taken from the TMR and the underway clean surface seawater intake (if shown to be clean on the transit to Heard). Samples will also be taken for Fe isotopic analysis (which is capable of distinguishing hydrothermal from background deep ocean Fe sources). Dissolved and particulate trace elemental subsamples will also be archived for ashore analysis by seaFAST-ICPMS. At sea measurements will also include microscopic examination of particles to look for hydrothermal minerals and volcanic glass fragments, and possibly dissolved gases indicative of high temperature water-rock interactions (CH_4, H_2S). We will also collect aerosol samples for trace elements to constrain the atmospheric delivery of iron and compare to sub-sea sources.

Detecting impacts on surface phytoplankton and bacterial production

Distributions of phytoplankton and their productivity will be estimated from underway shipboard measurements of chlorophyll fluorescence (a proxy for phytoplankton biomass) and fluorescence induction and relaxation (FIRe) measurements (which provide an estimate of phytoplankton photosynthetic competency). *In situ* measurements of seawater optical property profiles (radiometry, spectral backscatter, attenuation, and absorption, using the BO-Pak bio-optical instrument package) accompanied by collection of particle and pigment samples (from CTD Niskin bottles), will be undertaken to further characterize the microbial community. Continuous underway dissolved gas measurements (pCO_2, O_2/Ar, and $O2/N_2$ ratios) will be carried out to estimate net community production (on the approximately monthly timescale of air-sea gas exchange). Surface water nutrient distributions sampled from CTD Niskin samples will provide a minimum measure of seasonal net community production over the many months since deep mixing in the previous winter. These measures will be augmented by examination of satellite ocean colour images. This voyage will be the first to apply the FIRe, O_2/Ar, and O_2/N_2 techniques in the Kerguelen region.

Ocean circulation around Heard Island and across the eastern Indian Ocean sector of the Southern Ocean

To advance knowledge of circulation around Heard and McDonald islands, over the Central Kerguelen Plateau, and more broadly in the eastern Indian Ocean sector of the Southern Ocean, we will:

- Operate the shipboard ADCP and all available underway systems (thermosalinograph, meteorology, and biogeochemical systems) at all times.
- Deploy 20 drifters for NOAA's Global Surface Drifter Program and four ARGO floats from the Australian office of the International Argo Project.
- Utilise the lowered ADCP at every CTD station to determine full water column velocities, including vertical velocities.
- Employ the shipboard ADCP to document upper ocean currents.
- Generate a spatial view of the horizontal and vertical circulations across the Plateau that transport, mix, and advect hydrothermally-sourced fluids.

Ecology

Objective 1

Identification of important ecological areas in the southern and southeastern Indian Ocean with emphasis on the Central Kerguelen Plateau. The Kerguelen Plateau is an important area for higher marine predators such as seabirds and marine mammals. This is partly due to a limited number of possible breeding places for these (seals and seabirds require land to breed), but it is also a highly productive area, as relatively shallow water interrupts the flow of the Antarctic Circumpolar Current. McDonald Island and Heard Island each have been estimated to have over one million breeding pairs of macaroni penguins, plus a range of other breeding species. The Kerguelen Isles also have many breeding pairs of seabirds.

Some parts of the Central Kerguelen Plateau are likely to be more important than others, and so it will be useful to identify these areas and their importance. Some shallower banks in the area have previously been identified for their importance for fish, and these banks are likely to be important for other higher predators. Thus it will be important to visit some of these to determine their importance. However, it is difficult to visit the Plateau due to its remote location. Some important areas have been identified using larger predators such as seals and penguins from the Kerguelen Isles; however, it will be extremely valuable to also observe areas utilized by smaller species that are challenging to attach loggers to, and to species breeding locally on Heard and MacDonald islands, as these are rarely visited by ecologists undertaking studies using loggers. It will be most useful to visit banks at a range of distances from the islands to examine how distance from islands affects ecological significance.

To address Objective 1, we will conduct surveys of seabirds during hours of daylight while the vessel is underway. We will use standardised, accepted survey techniques.

Objective 1b

Examining distribution of seabirds over the Central Kerguelen Plateau to identify responses to increased oceanic iron if possible.

Objective 2

Mapping of distribution of cetaceans/mammals over the southern and southeast Indian Ocean, with emphasis on the Central Kerguelen Plateau. This will involve counting all sightings of mammals during daylight hours. These observations will be used in conjunction with observations from Objective 1 in identifying ecologically important areas, as well as contributing to databases of marine mammal distribution.

Objective 3

Mapping the distribution of marine debris over the southern and southeast Indian Ocean, with emphasis on the Central Kerguelen Plateau. This will contribute to a study by Dr Chris Wilcox and Dr Denise Hardesty of CSIRO.

Arts and Science

Science-Art (Charles Tambiah)

The goals include:

- Undertaking research on producing visual content inspired by voyage activities, scientific projects, and geographical environments for developing science-art outcomes for wider science engagement (including a major science-art exhibition in Canberra and perhaps Hobart).
- Undertaking research on advancing techniques in onboard science photography for documenting wider geology, rock samples, and biota during voyages.
- Exploring the opportunities and challenges of conducting interdisciplinary research, within the context of scientific voyages, to integrating science and art.

Visual Arts (Annalise Rees)

The objectives include:

- Observing shipboard activities including scientific research, crew operations, and shipboard life.
- Recording and documentation of all shipboard activities through observational drawing, and still/moving image and sound capture.
- Establishing an open dialogue between artistic and creative research being carried out onboard.
- Generating creative responses to observation of and participation in the shipboard experience including drawing, dance/movement, still/moving image, and sound.

Choreography (James Batchelor)

The aims include:

- Researching physical systems and processes of knowledge acquisition, with a particular focus on the relationship between empirical and theoretical understanding.
- Developing new chorographic approaches in response to the ship environment, working collaboratively with the science team and other artists.
- Researching choreographic concepts and images for new major performance work/s.
- Developing experimental film techniques in combination with choreographic research to create a film installation.
- Documenting processes and activities on the ship using film, photography, drawing, and sound recording.

Results

Seafloor, subseafloor, and water column mapping/geophysical characterisation

We mapped the seafloor and water column, and imaged the sub-seafloor around the McDonald Islands and Heard Island, and on Gunnari Ridge, as planned (Figures 1-4), revealing a wealth of detail for ~1,000 km^2 of seafloor that lacked multibeam coverage. Seafloor mapped around the McDonald Islands (Figure 3) was characterized by previously unknown numerous sea knolls interpreted as volcanic edifices, slumps, debris avalanches, current scour, current bedforms, and strong backscatter. The relatively small proportion of seafloor newly mapped around Heard Island (Figure 4) was characterized by some volcanic edifices, a major debris avalanche emanating from the Big Ben volcanic massif to the southwest of the Island, submarine canyons south of the Island, and strong backscatter. The portion of Gunnari Ridge seafloor that we mapped for the first time was dominated by a submarine canyon system, and was characterized by moderate to weak backscatter. A single crossing of Shell Bank showed multiple previously unknown sea knolls that we interpreted as volcanic edifices.

In the water column, using primarily the EK60 split-beam echosounder, we discovered >300 acoustic plumes emanating from the seafloor and sea knolls around the two island groups (e.g., Figures 5 and 6). The acoustic plumes typically ascended from the seafloor vertically from a few to tens of metres into the water column, and varied from tens to a few hundred metres in diameter. Repeat crossings of some acoustic plumes revealed temporal changes in their morphologies. Interspersing mapping and sampling, we sampled the water column over and around two acoustic plume fields, one east of the McDonald Islands (Figure 3, stations 20, 37-40) and one northeast of Heard Island ((Figure 4, stations 26, 32, 48-51), intensively when wind and sea state permitted. Post-voyage, we learned that the ME70 multibeam echosounder settings had not been changed from the deep water parameters of the previous 2015 voyage to shallow water parameters appropriate for our work around the islands, rendering these data – which had been anticipated to contribute significantly to the understanding of the 300+ acoustic plumes – not appropriate for all of our work around McDonald and Heard islands.

Sub-bottom profiling yielded zero to a few tens of metres of penetration on the Central Kerguelen Plateau. Northeast of Heard Island, some acoustic plumes were situated above previously unknown acoustic blank zones in the sub-bottom profiler data (Figure 7). The tops of these blank zones varied in stratigraphic level. Elsewhere in the global ocean, such blank zones have been sampled and confirmed to be gas- and/or fluid-charged zones in sediment. Around the McDonald Islands, the sub-bottom profiler did not penetrate seafloor of high acoustic impedance, and thus we could not observe blank zones beneath the many acoustic plumes there. Our seafloor and water column mapping of Gunnari Ridge did not reveal any anomalous seafloor features or acoustic plumes, respectively, and hence prospective hydrothermal targets for further investigation.

The gravimeter recorded data continuously throughout the voyage. In general, free-air gravity highs correlated with bathymetric highs. We had intended to deploy the magnetometer only on the long transits; however, because of a speed limitation of ~8 knots for its use, we did not deploy it at all. Maximising time over the Kerguelen Plateau and minimising time in transit were high priorities.

Due to a medical evacuation, we lost nine days of work over the Kerguelen Plateau, which eliminated planned surveying of Shell Bank from the voyage plan, although we did conduct one dredge there (Figure 1, station 17). The lost nine days constituted 25% of our planned work in the study area, and therefore had a substantial impact on achieving our scientific objectives.

Nature of submarine volcanoes and hydrothermal systems

We characterised the spatial distribution and morphology of submarine volcanoes and acoustic plumes emanating from the seafloor around Heard and McDonald islands using multibeam and multi-frequency split-beam echosounder data (Figures 2-4). Sub-bottom profiler data also aided in the characterisation of submarine volcanoes and other seafloor. We deployed the deep tow camera in two acoustic plume fields, one east of the McDonald Islands (Figure 3, stations 20, 37-40) and one northeast of Heard Island (Figure 4, stations 26, 32, 48-51). Due to a turbid water column, visibility was extremely limited northeast of the McDonald Islands, and we were unable to identify the source(s) of the acoustic plumes. The water column was also turbid north of Heard Island, but on the last day of work, using an inventive lateral deep tow camera sweep technique, we imaged bubbles emanating from the seafloor in multiple locations corresponding to acoustic plumes in the water column (Figures 8, 9).

We devoted intensive efforts with CTD/LADCPs (including particle backscatter sensor, nephelometer, and transmissometer), TMRs, ISPs, ORPs, and MAPR to sample one acoustic plume field east of the McDonald Islands (Figure 3, stations 20, 37-40) and one northeast of Heard Island (Figure 4, stations 26, 32, 48-51). Shipboard iron data hint that the former may have a hydrothermal origin, but shipboard evidence – primarily deep tow camera imagery, sub-bottom profiler data, and CTD data – suggest the origin of the latter to be biogenic gas. Neither of the two intensively studied acoustic plume fields was situated on submarine volcanoes; however, Smith-McIntyre grab samples from the two acoustic plume fields (Figures 2-4, stations 20, 26) yielded volcanogenic sediment from the local seafloor.

Our dredging program constituted the first seafloor sampling around the islands. We dredged rocks from five sea knolls interpreted to be submarine volcanoes, three around the McDonald Islands (Figures 2 and 3, stations 23, 24, 36), one north of Heard Island (Figures 2 and 4, station 34), and one on Shell Bank (Figure 1, station 17). We also undertook two successful dredges of a debris avalanche south of Heard Island that represents a sector collapse of the Big Ben volcanic massif (Figure 4, stations 29, 30). Shipboard descriptions of the dredged rocks indicate that the sea knolls around the McDonald Islands are compositionally similar to rocks of these islands, i.e., phonolitic, and that the sea knoll and debris avalanche around Heard Island are compositionally similar to Heard Island rocks, i.e., basaltic. Eight Smith-McIntyre grabs were deployed to sample seafloor material (Figures 2-4, stations 19, 20 (3), 22, 26 (2), 35), and all yielded volcanogenic sediment unsuitable for piston, gravity, or multi-coring. Thus we did not collect any piston, gravity, or multi-cores the entire voyage.

Detecting hydrothermal inputs to the ocean, and vertical water movements that deliver them to surface waters

We conducted a 12-station, full-depth CTD/LADCP/TMR transect extending from the Australia-Antarctic Basin across the northeast flank of the Central Kerguelen Plateau to the western side of the Central Plateau (Figure 1, stations 5-16). This transect, a repeat of KEOPS 'B' augmented to the northeast by crossing the Deep Western Boundary Current (DWBC), was intended to capture cross-Plateau gradients in water properties and biomass. Dissolved Fe, Mn, Fe(II), and H_2O_2 were determined at sea by flow injection analysis in samples taken from the TMR and the underway clean surface seawater intake. Shore-based analyses will investigate the export of hydrothermal minerals and elements in the DWBC, which scours the eastern side of the Plateau. Vertical velocities determined from LADCP data indicate upward flow in the deep waters for this transect and alternating upward and downward flow over the slope. Data from the slope stations show intrusions in temperature and salinity along with their transport by the horizontal velocities, which vary with depth. Internal waves were indicated over the slope. Further analyses will provide more insight into the internal wave field and the impacts of the DWBC impinging on rough Plateau bathymetry.

We attempted a reference station in deep waters presumed to be not fertilised with Fe from the Plateau or hydrothermal activity west of the McDonald Islands (Figure 1, station 18), but biomass turned out to be relatively high. A reference station in deep waters south of Heard Island (Figure 1, station 25), however, met with success in yielding high-nutrient, low-chlorophyll (HNLC) water.

As indicated, we sampled one acoustic plume field northeast of the McDonald Islands (Figure 3, stations 20, 37-40) and one north of Heard Island (Figure 4, stations 26, 32, 48-51) intensively with CTDs (including particle backscatter sensor, nephelometer, and transmissometer), TMRs, ISPs, ORPs, and MAPR. We discovered after the McDonald Islands work that both ORP units had not been working properly; they were subsequently repaired and operational for work on the acoustic plume field north of Heard Island. On the basis of shipboard reduced iron data, the McDonald Islands field may be hydrothermal in origin; however, on the basis of sub-bottom profiler data showing blank zones beneath the Heard Island field and deep tow camera footage of bubbles – and not high-temperature hydrothermal fluids – rising from the seafloor where the acoustic plumes are located, this field appears to be caused by shallow biogenic gas. Neither of the two intensively studied acoustic plume fields was situated on submarine volcanoes, but the Smith-McIntyre grab recovered samples of volcanogenic sediment from the seafloor source region of the two acoustic plume fields.

We conducted a second, full-depth CTD/LADCP/TMR transect consisting of seven stations east from Heard Island across the southernmost Central Kerguelen Plateau (Figure 1, stations 41-47). Again, we intended to capture cross-Plateau gradients in water properties and biomass. Shore-based analyses will investigate the potential transport of hydrothermal minerals and elements in the branch of the Antarctic Circumpolar Current that flows through the south-north bathymetric trough of the Central Kerguelen Plateau. During this transect, data indicate upwelling of cold, nutrient-rich waters from the canyons and troughs.

Our intention to 'fly' the TRIAXUS to prospect for hydrothermal systems near Heard Island and the McDonald Islands was foiled by several factors: shallow, rough bathymetry that would have put the vehicle at risk of colliding with the bottom; the entire water column being thoroughly mixed; wind and sea conditions that typically exceeded the safe deployment and recovery weather window for the vehicle; perceived limited availability of ship's fuel; and for the final and most promising opportunity, the need to cease work prematurely to undertake a medical evacuation.

Despite the development and availability of high-resolution physical oceanographic circulation model simulations, the absence of positive identification of iron-rich hydrothermal plumes precluded determining trajectories and dispersals of such plumes after leaving their source vents. However, our data indicate that circulation around the islands is dominantly tidal with a small mean current to the northeast.

Using a combination of CTDs, TMRs, ISPs, and sampling of the ship's trace-metal clean seawater supply, we acquired clean samples for shore-based analysis ($^3He/^4He$ anomalies, microscopic mineralogy, rare earth elements, macro-nutrients, Fe, Mn, dissolved and particulate elemental ratios, X-ray synchrotron mineralogy of particles, and other hydrothermal signatures). Samples were also taken for Fe isotopic analysis (which is capable of distinguishing hydrothermal from background deep ocean Fe sources). We also collected aerosol samples for trace elements to constrain the atmospheric delivery of Fe and to compare this to submarine sources. Dissolved and particulate trace elemental subsamples, plus those of trace element speciation, have been archived for ashore analysis by seaFAST-ICPMS. Through these shore-based geochemical and biogeochemical analyses, we aim to: a) identify whether the enrichments in trace metals are due to sedimentary resuspension, glacial melt/runoff, vertical mixing (e.g., upwelling) of deep waters, hydrothermal fluids, or delivery from the volcanic islands (or some combination); b) trace the mobility of the trace elements; and c) investigate the role this iron source plays in trace element biogeochemical cycling over and downstream of the broader the Kerguelen Plateau.

In summary, along two broadly east-west transects of the central plateau, dissolved iron was largely depleted (<0.2 nmol/L) in surface waters, with enrichment near the seafloor along the 'northern' (0.4-0.6 nmol/L) and 'southern' (0.6-0.9 nmol/L) lines (Figure 10). Conversely, in the shallow (100-200 m deep) waters near Heard and McDonald Islands, dissolved iron was elevated (1.0-3.0 nmol/L) throughout the well-mixed water column (Figure 11a). Interestingly, the lower redox form of iron (dissolved iron(II)), was also elevated (up to 0.6 nmol/L) near observed elevated acoustic plume signals (suggesting potential gas and/or fluid inputs) close to the McDonald Islands, accounting for up to 30% of the dissolved iron concentration, indicative of processes promoting reduction of iron (Figure 11b). This feature was not as obvious in the samples collected near elevated acoustic plume signals close to Heard Island.

In relation to the scientific objectives from the Voyage Plan, our preliminary results indicate the following:

1. Iron availability limits phytoplankton production in the surface waters over the central Kerguelen Plateau in summer. The dissolved iron stock from winter mixing is drawn down (by approximately 0.3-0.4 nmol/L) earlier in the season (spring), and likely incorporated into biological particles during the time of our survey (late summer).
2. We have identified that nearshore, shallow (<200 m) waters of Heard and McDonald islands contain elevated and non-limiting concentrations of dissolved iron.
3. Despite the identification of fields of acoustic plumes from water column mapping proximal to the islands, we have not as yet been able to demonstrate these are associated with submarine volcanoes or link elevated iron to hydrothermal fluids.
4. Interestingly, the elevated levels of dissolved iron do not result in the accumulation of elevated biomass around Heard and McDonald islands (see below).
5. Our earlier work (KEOPS expeditions) has shown that iron supply in waters over the Central and Northern Kerguelen Plateau plays a major role in stimulating phytoplankton biomass production in downstream waters. For the HEOBI expedition, the far-field effects of the elevated iron near Heard and McDonald islands on regional biogeochemistry are not yet known.
6. The survey and transects conducted during HEOBI have together delivered advances to physical and biogeochemical oceanographic understanding of lateral and deep-surface exchanges of trace elements in the Kerguelen-Heard region, regardless of whether hydrothermal signals will be identified in future analyses.

Detecting impacts on surface phytoplankton and bacterial production

Assessment of biological responses to possible volcanic influences was based on determining spatial distributions of phytoplankton and bacterial properties over the plateau (planned to be primarily via TRIAXUS tows), augmented by experiments on responses of these organisms to additions of particles and seawater sampled from volcanoes near McDonald and Heard islands. Neither of these approaches was definitive, because multiple iron sources were present over the plateau (from sediments, upwelled deep water, and glacial runoff), and hydrothermal fluids could not be obtained to be used in the experiments. The curtailing of the voyage also affected the assessment of biological impacts; in particular, only 5 rather than the hoped for 90 miles of Triaxus tows were achieved over the Central Kerguelen Plateau.

Much of the assessment of biological responses will only become clear after further laboratory analyses are completed, but a few preliminary results have emerged:

1. In the shallow waters studied in detail in the vicinity of Heard and especially McDonald islands it appears that biological responses were insufficient to overcome upwelling processes, so that degassing of CO_2 from the ocean to the atmosphere dominated over biologically mediated uptake. In combination with strong time-varying circulation in this area, these advective signals preclude use of the gas tracers to quantify net community production.
2. The occasional (limited by cloud cover) ocean colour images obtained during the voyage suggest only moderate phytoplankton biomass in the shallow waters in the vicinity of Heard and McDonald islands in comparison to waters of the deeper Central Kerguelen Plateau to their north. This is consistent with satellite decadal average observations. This is not necessarily a counter argument to the hypothesis that these volcanic islands fuel iron inputs that increase phytoplankton productivity, for multiple reasons. One, it is possible that the satellite images are biased towards low biomass estimates, because they are based on open ocean algorithms that may be inappropriate for these coastal waters, where the BO-Pak backscatter observations have identified high particle loads (probably from both resuspended

sediments and glacial meltwater inputs) associated with the low chlorophyll fluorescence. Further analysis of these and other voyage data and satellite algorithms may shed some light on this possibility. Two, the lack of biomass accumulation may reflect processes that dilute (e.g. the strong upwelling) or remove (abundant shallow water grazing communities) biomass more rapidly than over the deeper Central Kerguelen Plateau. Preliminary results from the FIRe instrument argue for this possibility, in that high ratios of variable to maximum fluorescence (Fv/Fm) were observed around Heard and especially McDonald islands, suggesting optimally healthy phytoplankton growing at high rates (Figure 12).

3. While healthy phytoplankton around the volcanic islands may reflect local Fe inputs, it remains unknown whether recent volcanism has played a significant role in the control of the large-scale phytoplankton plume over and downstream the Kerguelen Plateau. One potentially relevant observation is that seasonal chlorophyll accumulations monitored by satellite were not higher during the period when the McDonald Islands doubled in subaerial size (around year 2000) than in other years.
4. Nutrient distributions measured during HEOBI were typical of late summer conditions on the Kerguelen Plateau, showing evidence of substantial nutrient uptake by diatoms. Around Heard and McDonald islands surface nutrient concentrations were elevated, suggesting vigorous vertical mixing and less evidence for net biological removal of nutrients. Silicate concentrations around Heard and McDonald islands were consistent with vertical mixing of the regional profile, and do not require a hydrothermal contribution.
5. Incubation experiments with suspended particles collected around the McDonald Islands suggest a high potential for regeneration (heterotrophic bacteria) of dissolved iron compared to particles originating from off-plateau waters.

Ocean circulation around Heard Island and across the eastern Indian Ocean sector of the Southern Ocean

The shipboard ADCP and all available underway systems (thermosalinograph, meteorology, and biogeochemical systems) operated at all times. These data are adding valuable *in situ* observations of the physical and biological structure of upper-ocean currents around Heard and McDonald islands, and between the islands and Australia, including the inbound and outbound transits across the Antarctic Circumpolar Current fronts. Every CTD was accompanied by the lowered ADCP to measure full water column velocity. The shipboard ADCP have provided information on upper ocean currents. The well-mixed hydrography over the Central Kerguelen Plateau precluded the sustained presence of internal waves. Typically, upwelling events cooled the bottom of the water column, setting up a density gradient. At these times, internal waves could develop and induce mixing. However, strong wind events occurred every few days. These wind events commonly mixed the entire water column, practically homogenizing the water column or leaving it weakly stratified. Internal waves cannot exist in a homogenized water column. When weak stratification remained after a wind mixing event, any internal waves would have large amplitudes on the order of the water depth and their energy would propagate nearly vertically. Consequently, internal waves and their mixing occurred sporadically and mixing of the water column was dominated by wind-induced mixing. Overall, circulation around Heard and McDonald islands was dominantly tidal, with velocities of 15 – 50 cm/s. The northward component was 6 cm/s. The entire water column in depths less than ~200 m was typically well mixed.

Ecology

During the voyage, we undertook 2,581 transect counts of seabirds. On these counts, we recorded 61 species of seabird. While over the Central Kerguelen Plateau, we made 1,015 transect counts and recorded 31 species (Figure 13). Coverage was good over the area around Heard and McDonald islands, with some coverage also of Gunnari Ridge. We also covered some deeper parts of the Central Kerguelen Plateau. The medical evacuation prevented a planned intensive survey of Shell Bank, so no observations were possible on this bank more distant from the islands. Nevertheless, initial analyses indicate that at least some species exhibit geographic preferences. Further analyses, incorporating environmental variables, should further elucidate this.

Identifying relationships between seabird distribution and iron supply seems unlikely at this stage.

We photographed penguin colonies on McDonald Island extensively. We will use the photographs to estimate the populations of macaroni and king Penguins on the Island. This is significant information as penguin populations on the Island have only been counted twice previously, once in the 1970s and once in the 1980s. Macaroni penguins apparently abandoned the Island temporarily after the 1990s eruption(s), while king penguins were not previously present.

We made 31 sightings of sea mammals away from the immediate vicinity of Heard and McDonald islands (fur seals were sufficiently common in waters around Heard and McDonald Island to be treated using the same method as for seabirds). Sightings included five species of whales and three species of dolphins. The most intriguing series of sightings comprised seven sightings (approximately eight animals) of blue whales over Gunnari Ridge on 9/10 February (another sighting on 21 January may have been in the same area, as it was approximately 1° north and 1° west of the February sightings).

We made 18 sightings of marine debris during the voyage. Most were close to the coast of Western Australia.

Arts and Science

Substantial research was undertaken for choreography, drawing, photography, and videography that are expected to result in contemporary dance performances, exhibitions, and presentations at National Science Week and other forums.

Science-Art (Charles Tambiah)

Activities, results, and outputs include:

- Collection of unique visual content for development in post-voyage studio-lab research and scholarly studies in science photography and science engagement.
- Development of base-layer content and collaborations for delivering on the planned science-art exhibition.
- Research and testing of science photography techniques, leading to voyage contributions of a ‘rock poster’ (Appendix 4) and ‘non-rock by-catch ebooklet’ (Appendix 5).
- Extensive visual documentation of Heard and McDonald islands geology, using specialised panoramic photography techniques that will foster post-voyage interpretation of previously unrecorded geological processes (undertaken by Richard Arculus).

Visual Arts (Annalise Rees)

Research undertaken and shipboard experiences will:

- Contribute significantly to PhD studies – focus on drawing based methodologies used to record and trace phenomena and human interactions in the world (Appendix 6).
- Contribute to at least of three public exhibitions showing in Tasmania and interstate in 2016/2017.
- Contribute to public performances to Tasmanian and interstate audiences in 2016-2017, with the potential to tour nationally/internationally.
- Be communicated to public audiences as part of 2016 Science Week forums in Tasmania and South Australia.
- Contribute to public awareness and knowledge of scientific research in the Southern Ocean.

Choreography (James Batchelor)

Outcomes included:

- Development of a range of physical ideas that will be continued in future studio practice. He devised a method of generating movement in response to touch, surface, and textures, creating physical maps of various spaces and structures in the ship (Appendix 7). He has also developed movement that responds to the data, samples, and images collected by the science team. In contrast to the touch-based research, these ideas respond to a conceptual understanding of spaces that cannot be sensed by the body.
- Identification of several potential concepts for new installations and performances. One such idea involves utilising light and shadows to create a dynamic and immersive performance space. Responding to the unique light conditions on the *Investigator*, mobile structures and fixed light sources will create a dynamic space of light and shadows. Movement of the performers and audience will create silhouettes of new and unknown structures, accompanied by an original sound design sourced from recordings made on the expedition. This will be researched further across residencies in 2016 at Tasdance in Launceston and Artshouse in Melbourne, with expected public outcomes in 2017.
- In documenting activities on the *Investigator*, James collected over 16 hours of film material, over 500 photographs, and 84 unique sound recordings. Post- expedition, James will edit the film material to develop a screen-based media work.

Voyage Narrative

RV *Investigator* voyage IN2016_V01 – Heard Earth-Ocean-Biosphere Interactions (HEOBI) – may be divided into three distinct components: seafloor hydrothermal system prospecting, sensing/sampling, and imaging; plateau water column transects with reference sites; and transits. During all three components, we acquired data from the multibeam systems, multi-frequency split-beam echosounders, sub-bottom profiler, gravimeter, thermosalinograph, aerosol sampling, air chemistry sampling, underway seawater analyses, XBTs, atmospheric underway sensors, and biological oceanography underway sensors. We also launched robotic floats for the Australia-India Strategic Research program and *Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM)* project, and drifters for the US National Oceanic and Atmospheric Administration's (NOAA) Global Drifter Program. The first two components comprised the core of the scientific investigations, and they intermingled during the 26 days that we were able to devote to work over the Kerguelen Plateau. Transits, including equipment testing and medical evacuation diversions from a great circle route, consumed 24 days. See Appendix 1 for the full chronological list of stations and transits, and the activities undertaken at each station and during transits.

Seafloor hydrothermal system prospecting, sampling, and imaging

Our principal geographic area of focus was Heard and McDonald islands (HIMI) (Figures 2-4), plus less than a day at Gunnari Ridge east of Heard Island. The primary prospecting tools for seafloor hydrothermal systems were the multibeam systems and multi-frequency split-beam echosounders. With these instruments, we identified approximately 300 acoustic plumes emanating from the seafloor, as distinct from acoustic plumes entirely within the water column that were interpreted as being biological. Weather played a significant role in determining which operations were possible, but the general pattern was to prospect with acoustics, and take advantage of weather windows appropriate for water sensing/sampling and deep tow camera work. Both prospecting and sensing sampling were constrained around the islands by the need to exit the HIMI Inner Marine Reserve approximately every 24 hours to discharge treated wastewater from RV *Investigator*.

The overall strategy of water sensing/sampling consisted of 1) ringing both McDonald Islands and Heard Island with CTDs (including particle backscatter sensor, nephelometer, and transmissometer), TMRs, ISPs, ORPs, MAPR, and BO-Pak deployments, and 2) undertaking the same deployments in a cross pattern of five stations centred on two acoustic plume field sites, one northeast of the McDonald Islands, and one north of Heard Island. Furthermore, at each of the two acoustic plume field sites, we took Smith McIntyre grabs of seafloor sediment, and at the site north of Heard, we did both CTD and deep tow camera sweeps across the acoustic plume field.

Plateau water column transects with reference sites

We undertook two water column transects across the Central Kerguelen Plateau (Figure 1) using CTD (including particle backscatter sensor, nephelometer, and transmissometer) and TMR rosettes, and the BO-Pak. The more northerly of the two transects extends from the Australian-Antarctic Basin across the Deep Western Boundary Current (DWBC) to join and repeat the KEOPS transect. The more southerly transect extends east from Heard Island into a north-south bathymetric trough (i.e., between stations 14 and 47, Figure 1) east of Gunnari Ridge.

Transits

Transits totalled 24 days (see Voyage Track). During the 10-day outbound transit from Fremantle to the Kerguelen Plateau, we tested the CTD, TMR, ISPs, BO-Pak, and Triaxus in two eddies and across the Polar Front to ensure that everything was operational for work on the Kerguelen Plateau (Figure 14). During the 14-day transit from Heard Island to Hobart via Albany (medical evacuation) from 13 to 27 February, we did not conduct any station nor did we tow any instruments; only underway systems acquired data.

Summary

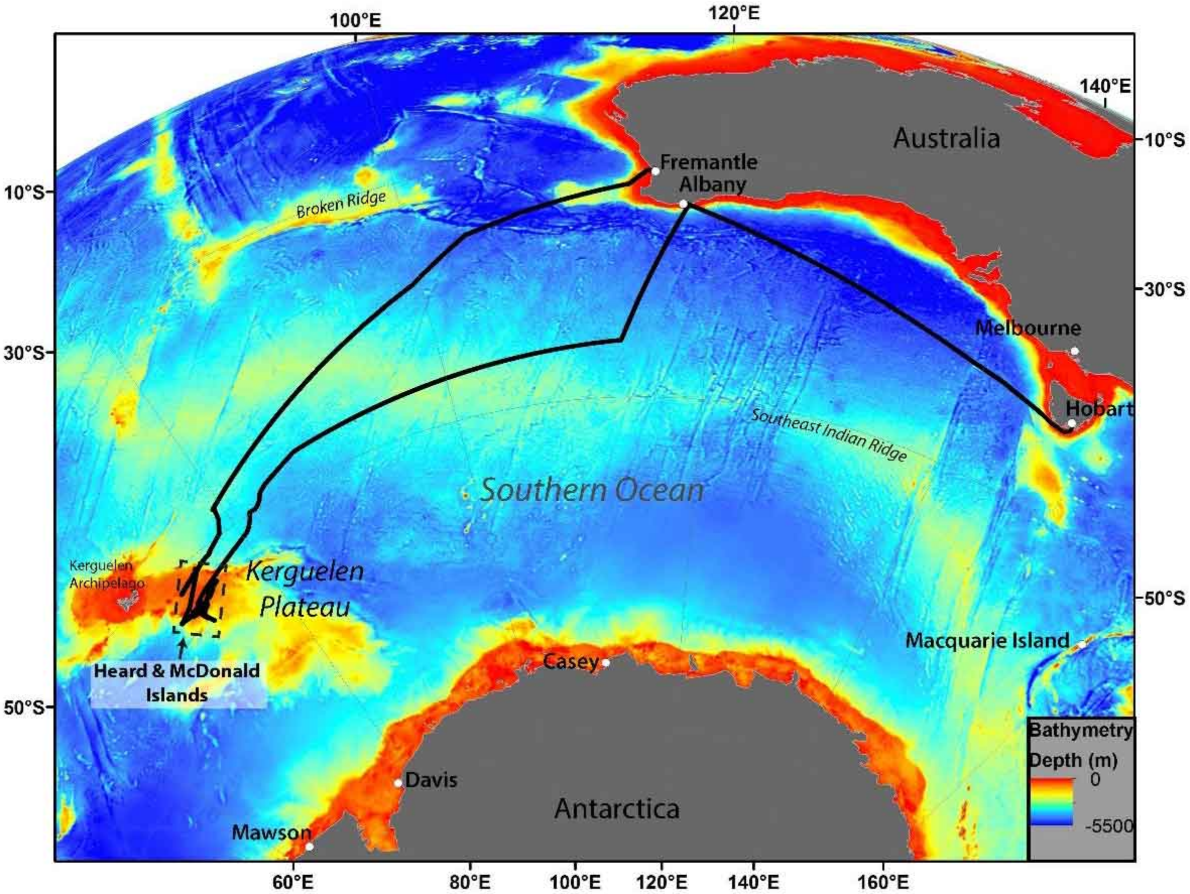
The scientific achievements of this ambitious and challenging multidisciplinary research endeavour are manifold. Spanning geoscience, biogeochemistry, physical oceanography, and ecology, the data acquired during the voyage are yielding significant insights into relationships between active volcanism on the Central Kerguelen Plateau and phytoplankton productivity down-current of this volcanism. We have learned that Heard and McDonald islands, and potentially active submarine volcanoes in their vicinity, constitute a major source of iron in the Southern Ocean, and that phytoplankton production around the islands is high.

Significant initial shipboard results include:

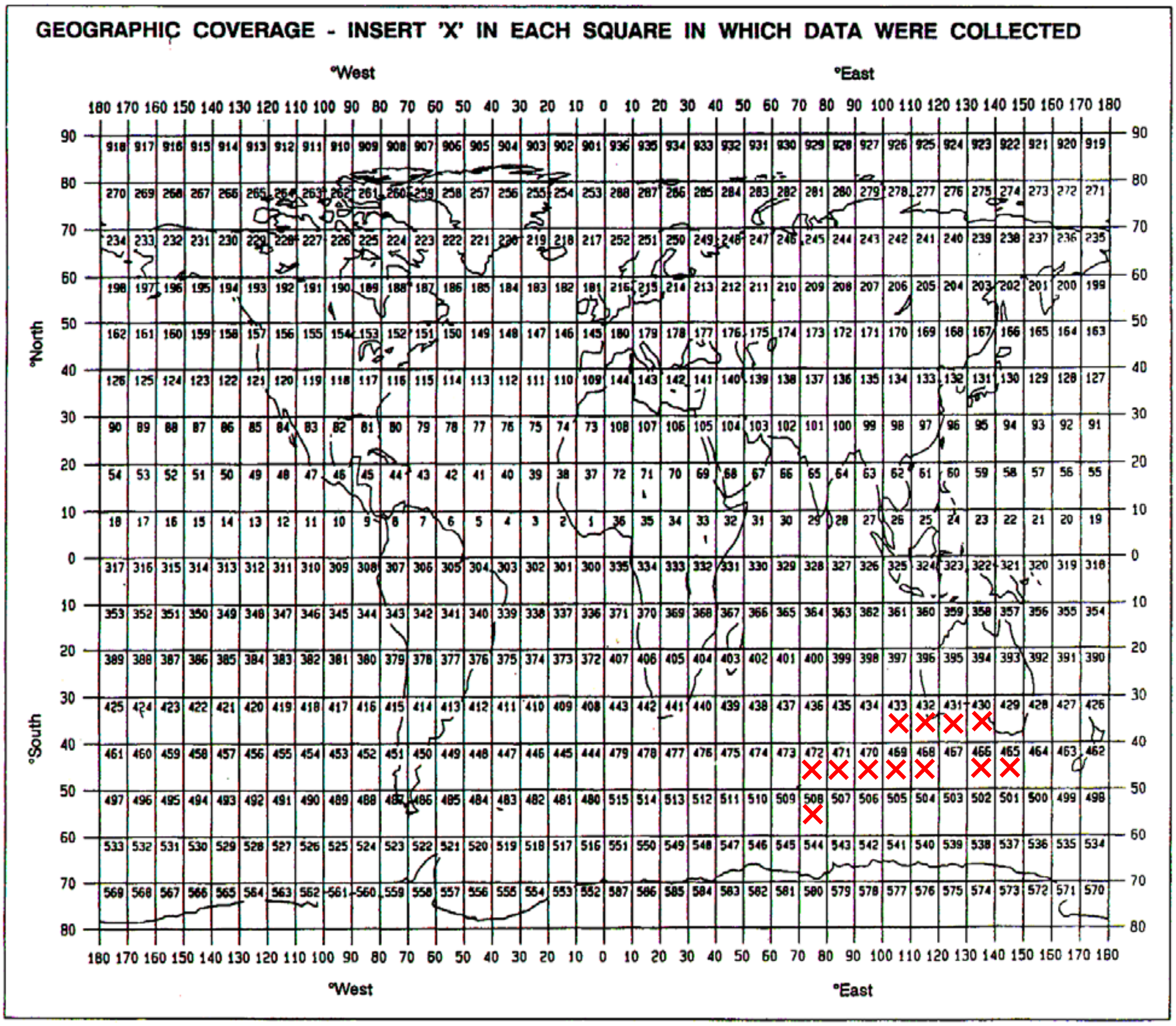
1. The discovery of numerous volcanic sea knolls around Heard and McDonald islands, the compositions of which correspond to those of the most proximal islands.
2. The identification of a submarine debris avalanche southwest of Heard Island that apparently originated from a sector collapse of the Big Ben volcanic massif.
3. The discovery of >300 acoustic plumes emanating from the seafloor around McDonald and Heard islands. We hypothesize that those around the McDonald Islands are predominantly hydrothermal in origin. In contrast, we confirmed that at least some of the acoustic plumes northeast of Heard Island originate from bubbles, presumably of biogenic methane, whereas others around Heard Island may be hydrothermal in origin.
4. The detection of gas- and/or fluid-charged zones in sediment northeast of Heard Island that correspond in some cases to bubbles emanating from overlying seafloor.
5. The identification of elevated, non-limiting concentrations of dissolved iron in shallow (<200 m) waters around Heard and McDonald islands.
6. The determinations of non-elevated biomass and optimally healthy phytoplankton growing at high rates around Heard and McDonald islands.
7. Evidence of substantial nutrient uptake by diatoms.
8. Incubation experiments with suspended particles from McDonald Islands waters suggesting a high potential for regeneration of dissolved iron compared to that of particles originating from off-plateau waters.
9. Upwelling events arising from canyons on the Central Kerguelen Plateau or over the Plateau's northeast flank carry cold, nutrient-rich water to the region.
10. Frequent strong wind events mix surface waters warmed by insolation with colder bottom waters, homogenising the water column.

Much further shore-based research has commenced and will continue for several years. Our ultimate aim is to identify, quantify, and model the sources, mechanisms, and processes in the Heard and McDonald islands area that supply iron to the Southern Ocean, and thereby to advance geoscientific, biogeochemical, and physical understanding of the Kerguelen Plateau region as well as the Southern Ocean beyond. Further shipboard work, especially utilising the capabilities of a state-of-the-art remotely-operated vehicle (ROV), will be necessary to advance understanding of potential hydrothermal systems associated with active underwater volcanoes around the islands and elsewhere on the Kerguelen plateau. This future work will further illuminate the linkages between active solid Earth volcanism, iron in the Southern Ocean, and phytoplankton.

Voyage Track



Marsden Squares



Moorings, bottom mounted gear and drifting systems

ITEM #	PI	APPROXIMATE POSITION						DATA TYPE	DESCRIPTION				
		LATITUDE			LONGITUDE								
		deg	min	N/S	deg	min	E/W		date	type	Site ID	op #	category
1	Robertson	36	21.39	S	103	38.50	E	D05	11/01/16	Drifter 145727 / WMO 56565	transit	DR-01	deployed
2	Robertson	36	21.39	S	103	38.50	E	D05	11/01/16	Drifter 145743 / WMO 56566	transit	DR-01	deployed
3	Trull	36	21.41	S	103	38.12	E	D06	11/01/16	Bio-Argo float 0391	transit	A-01	deployed
4	Robertson	39	29.39	S	99	24.43	E	D05	10/01/16	Drifter 145732 / WMO 56567	transit	DR-02	deployed
5	Robertson	38	29.39	S	99	24.43	E	D05	10/01/16	Drifter 145726 / WMO 56569	transit	DR-02	deployed
6	Trull	39	29.02	S	99	24.79	E	D06	12/01/16	Bio-Argo float 0528	Site 0002	A-02	deployed
7	Rosso	39	29.36	S	99	24.58	E	D06	13/01/16	SOCCOM float 9749	transit	SOC-01	deployed
8	Robertson	44	51.80	S	87	28.94	E	D05	15/01/16	Drifter 145712 / WMO 56602	transit	DR-03	deployed
9	Robertson	44	51.80	S	87	28.94	E	D05	15/01/2016	Drifter 145713 / WMO 56603	transit	DR-03	deployed
10	Trull	44	50.70	S	87	31.45	E	D06	15/01/16	ARGO float 7371	transit	A-03	deployed
11	Trull	47	6.83	S	82	9.46	E	D06	16/01/16	ARGO float 7372	transit	A-04	deployed
12	Rosso	48	17.61	S	79	26.81	E	D06	17/01/16	SOCCOM float 9645	Site 0004	SOC-02	deployed
13	Robertson	48	17.41	S	79	26.83	E	D05	17/01/16	Drifter 145721 / WMO 16561	Site 0004	DR-04	deployed
14	Robertson	48	17.41	S	79	26.83	E	D05	17/01/2016	Drifter 145724 / WMO 16562	Site 0004	DR-04	deployed
15	Rosso	49	52.19	S	78	37.09	E	D06	18/01/16	SOCCOM float 9757	Site 0005	SOC-03	deployed
16	Trull	49	52.08	S	78	37.13	E	D06	18/01/16	ARGO float 7373	Site 0005	A-05	deployed
17	Robertson	54	10.57	S	73	38.86	E	D05	1/02/16	Drifter 145744 / WMO 56604	Site 0025	DR-05	deployed
18	Robertson	54	10.57	S	73	38.86	E	D05	1/02/16	Drifter 145759 / WMO 56605	Site 0025	DR-05	deployed
19	Robertson	53	11.90	S	73	5.36	E	D05	1/02/16	Drifter 145708 / WMO 56606	transit	DR-06	deployed
20	Robertson	53	11.91	S	73	5.36	E	D05	1/02/16	Drifter 145709 / WMO 56608	transit	DR-06	deployed
21	Robertson	52	41.24	S	75	0.02	E	D05	9/02/16	Drifter 145750 / WMO 56904	transit	DR-07	deployed

ITEM #	PI	APPROXIMATE POSITION						DATA TYPE	DESCRIPTION				
		LATITUDE			LONGITUDE								
		deg	min	N/S	deg	min	E/W		date	type	Site ID	op #	category
22	Robertson	52	41.17	S	75	0.18	E	D05	9/02/16	Drifter 145762 / WMO 56905	transit	DR-07	deployed
23	Robertson	52	21.84	S	75	12.07	E	D05	10/02/16	Drifter 145733 / WMO 56609	transit	DR-08	deployed
24	Robertson	52	21.84	S	75	12.00	E	D05	10/02/16	Drifter 145734 / WMO 56610	transit	DR-08	deployed
25	Robertson	52	21.89	S	75	11.98	E	D05	10/02/16	Drifter 145735 / WMO 56901	transit	DR-08	deployed
26	Robertson	52	21.84	S	75	11.96	E	D05	10/02/16	Drifter 145736 / WMO 56902	transit	DR-08	deployed
27	Robertson	51	43.74	S	77	10.60	E	D05	13/02/16	Drifter 145771 / WMO 56907	transit	DR-09	deployed
28	Robertson	51	43.74	S	77	10.60	E	D05	13/02/16	Drifter 145773 / WMO 56908	transit	DR-09	deployed
29	Trull	51	43.71	S	77	11.58	E	D06	13/02/16	ARGO float 7374	transit	A-06	deployed
30	Trull	51	35.35	S	77	42.86	E	D06	13/02/16	ARGO float 7382	transit	A-07	deployed

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 on last page	DESCRIPTION
1.	Coffin	13,431.172	Line kilometres	G74	Multibeam echosounder bathymetric data: EM122 Bathymetry, backscatter, water column data.
2.	Coffin	5,383.676	Line kilometres	G74	Multibeam echosounder bathymetric data: EM710 Bathymetry, backscatter, water column data.
3.	Coffin	16,220.8	Line kilometres	G27	Gravity data
4.	Coffin	16,220.8	Line kilometres	G74	ME70 bioacoustic multibeam echosounder water column data
5.	Coffin	16,220.8	Line kilometres	G73	EK60 bioacoustic singlebeam echosounder water column data
6.	Coffin	16,220.8	Line kilometres	G73	Sub-bottom profiler data
7.	Coffin	8	Drops	H11	XBT; sound-velocity profiles; salinity/depth
8.	Robertson	53	Rosettes	B02/D71/H10	CTD/LADCP; 5 cancelled/aborted: (CTD-03, -19, -37, -42, and -50)
9.	Robertson	1	Rosette	B02/D71/H10	CTD/LADCP; TO-YO (CTD-32)
10.	Robertson	1	Rosette	B02/D71/H10	CTD/LADCP; NO-YO (CTD-54)
11.	Bowie	40	Rosettes	P02	TMR
12	Bowie	11	Stations	P01	ISP (11 stations; 51 total pumps)
13.	Wojtasiewicz	35	Stations	B02/B08/B09/ D71/H10	BO-Pak (bio-optical sensor; Seabird19 plus CTD)
14.	Carey/Chase	9	Dredges	G01	Rock Dredge; 1 dredge lost
15.	Carey/Chase	8	Grabs	G02	Smith McIntyre Grab
16.	Trull/Chase	20	Towed nautical miles	B02	Triaxus tow T-01; T, S, O_2, NO_3, fluorescence, backscatter, transmission, LOPC, FvFm, ORP4CTD-03 (oxidation reduction potential), Minimone (miniaturised water sampler - iron), SUNA (submersible ultra-violet spectrometric nitrate detector), FIRe (fluorescence induction and relaxation)

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list on last page	DESCRIPTION
17,	Trull/Chase	80	Towed nautical miles	B02/H90/ H24/B02	Triaxus tow T-02; T, S, O_2, NO_3, fluorescence, backscatter, transmission, LOPC, ORP4CTD-03 (oxidation reduction potential), Minimone (miniaturised water sampler - iron), SUNA (submersible ultra-violet spectrometric nitrate detector), FIRe (fluorescence induction and relaxation)
18.	Trull	0	Towed nautical miles	B02	Triaxus tow T-03; malfunction – no data
19.	Trull/Chase	50	Towed nautical miles	B02/H90/ H24	Triaxus tow T-04; T, S, O_2, uv-NO_3, fluorescence, backscatter, transmission, LOPC, nephelometer, ORP4CTD-03 (oxidation reduction potential), Minimone (miniaturised water sampler - iron), SUNA (submersible ultra-violet spectrometric nitrate detector)
20.	Trull/Chase	5	Towed nautical miles	B02/H24/ H90	Triaxus tow T-05; T, S, O_2, uv-NO_3, fluorescence, backscatter, transmission, LOPC, nephelometer, MAPR66 (miniature autonomous plume recorder, ORP4CTD-03 (oxidation reduction potential), SUNA (submersible ultra-violet spectrometric nitrate detector)
21.	Bowie	15	Sample Filters	M71	Aerosol trace elements
22.	Trull	16,220.8	Underway	B02	Fluorometer
23.	Blain	16,220.8	Underway	H21	Optode
24.	Trull	16,220.8	Underway	H11	TSG (thermosalinograph)
25.	Swadling	1	Net	B08/B09	Dip net; zooplankton
26.	Chase	22	Deployments	H90	MAPR66 (miniature autonomous plume recorder); 3 x camera tows (TC-03, TC-05, TC-06); 18 x CTD (CTD-36, CTD-38 to -44, CTD-51 to -55); 1 x TRIAXUS (T-05) (see row 20 above)
27.	Chase	28	Deployments	H90	ORP (oxidation reduction potential); ORP4CTD-09 deployed on 28 x CTD (CTD-02, -04, -05, -07 to -18, -20 to -32)
28.	Chase	25	Deployments	H90	ORP (oxidation reduction potential); 21 x CTD (CTD-33 to -36, CTD-38 to 055)

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list on last page	DESCRIPTION
					ORP4CTD-03 deployed on 4 x TRIAXUS (T-01, -02, -04, -05) (see rows 16, 17, 19, and 20 above)
29.	Trull	2	Deployments	B02	FIRe (fluorescence induction and relaxation) 2 x TRIAXUS (T-01, T-02); in underway seawater lab from 28 Jan to 3 March (see rows 16 and 17 above)
30.	Trull	16,220.8	Underway	H90	EIMS (equilabrator inlet mass spectrometry) Installed in the underway seawater lab.
31.	Obernosterer	13	Stations	B07/B08	Microbial activity (respiration, heterotrophic production) and diversity (microbial abundance, bacterial/phytoplankton diversity, metatranscriptomics); DOC characterization
32.	Hindell	51	Days	B25/B26	Daily bird and mammal observations.

Curation Report

Item No.	DESCRIPTION
1.	Archived by MNF, AODN, Geoscience Australia, NOAA NCEI
2.	Archived by MNF, AODN, Geoscience Australia, NOAA NCEI
3.	Archived by MNF, AODN, Geoscience Australia, NOAA NCEI
4.	Archived by MNF, AODN
5.	Archived by MNF, AODN
6.	Archived by MNF, AODN, Geoscience Australia, NOAA NCEI
7.	Archived by MNF, AODN, Geoscience Australia, NOAA NCEI
8.	Archived by MNF, AODN, PANGEA, GEOTRACES; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
9.	Archived by MNF, AODN, PANGEA, GEOTRACES; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
10.	Archived by MNF, AODN, PANGEA, GEOTRACES; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
11.	Archived by MarLIN, GEOTRACES GDAC
12.	Archived by MarLIN, GEOTRACES GDAC

Item No.	**DESCRIPTION**
13.	Archived by CSIRO O&A
14.	Archived by UTAS, CSIRO O&A
15.	Archived by UTAS, CSIRO O&A
16.	Archived by MNF, AODN, CSIRO O&A
17.	Archived by MNF, AODN, CSIRO O&A
18.	N/A
19.	Archived by MNF, AODN, CSIRO O&A
20.	Archived by MNF, AODN, CSIRO O&A
21.	Archived by IMAS, GEOTRACES GDAC
22.	Archived by MarLIN, GEOTRACES GDAC
23.	Archived by CYBER
24.	Archived by MNF, AODN
25.	Archived by IMAS
26.	Archived by IMAS, AODN, CSIRO O&A; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
27.	Archived by MNF, AODN, CSIRO O&A; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
28.	Archived by MNF, AODN; biological samples, collected for particle and plankton characterization, will be destroyed during shore-based laboratory analyses.
29.	Archived by MNF, AODN
30.	Archived by CSIRO O&A
31.	Archived by CYBER
32.	Archived by IMAS

Personnel List

	Name	Organisation	Role
1.	Prof Millard (Mike) F Coffin	UTAS/IMAS	Chief Scientist
2.	Brett Muir	MNF	Voyage Manager
3.	Prof Richard Arculus	ANU/RSES	Alternate/Deputy/Co-Chief Scientist
4.	A/Prof Andrew Bowie	UTAS/IMAS/ACE CRC	Co-Chief Scientist/Lead PI Biogeochemistry
5.	Dr Robin Robertson	UNSW/ADFA	Lead PI Physical Oceanography
6.	Prof Stéphane Blain	UPMC/CNRS/LOMIC	Biogeochemistry
7.	Hugh Barker	MNF	DAP Support
8.	James Batchelor	Ausdance ACT	Choreography
9.	Anna Bradney	ANU/RSES	Geochemistry
10.	A/Prof Zanna Chase	UTAS/IMAS	Biogeochemistry
11.	Frances Cooke	MNF	GSM Support
12.	Hugh Doyle	UTAS/ACE CRC	TRIAXUS
13.	Evan Draayers†	UTAS/SPS-ES	Geology
14.	Dr Lloyd Fletcher	Aspen Medical	Doctor
15.	Jodi Fox†	UTAS/FSET/SPS-ES	Geology
16.	Fernando Arce Gonzalez†	UTAS/IMAS	Ecology
17.	Pete Harmsen	MNF	Cinematography/Photography
18.	Paul Hartlipp†	UNSW/ADFA	Physical Oceanography
19.	Thomas Holmes†	UTAS/IMAS/ACE CRC	Biogeochemistry
20.	Mark Lewis	MNF	Mechanical Technical Support
21.	Dr Tara Martin	MNF	GSM Support
22.	Dr Pier van der Merwe	UTAS/ACE CRC	Biogeochemistry
23.	Nicole Morgan	MNF	SIT Support
24.	Dr Ingrid Obernosterer	CNRS/LOMIC	Biogeochemistry
25.	Habacuc Perez-Tribouillier†	UTAS/IMAS	Biogeochemistry
26.	Nicholas Polmear	UTAS/IMAS	Geophysics
27.	Lavenia Ratnarajah†	UTAS/IMAS/ACE CRC	Biogeochemistry
28.	Mark Rayner	MNF	Hydrochemistry Support
29.	Annalise Rees†	UTAS/FA	Visual Art
30.	Dr Tim Reid	UTAS/IMAS	Ecology
31.	Dr Isabella Rosso	UCSD/SIO	Physical Oceanography
32.	Kendall Sherrin	MNF	Hydrochemistry Support
33.	Erica Spain††	UTAS/IMAS	Geophysics
34.	Charles Tambiah†	ANU/RSES/SA	Science-Art
35.	Manon Tonnard†	UBO/UTAS/IMAS/ACE CRC/UBO/IUEM	Biogeochemistry
36.	Prof Tom Trull	CSIRO/ACE CRC	Biogeochemistry
37.	Aaron Tyndall	MNF	SIT Support
38.	Dr Bozena Wojtasiewicz	CSIRO	Bio-optics
39.	Sally Watson†	UTAS/IMAS	Geophysics
40.	Dr Kathrin Wuttig	UTAS/ACE CRC	Biogeochemistry

†PhD student (11), ††Masters student (1)

Key: ACE CRC – Antarctic Climate & Ecosystems Cooperative Research Centre; ADFA – Australian Defence Force Academy; ANU - Australian National University; Ausdance ACT - Australian Dance Council – Ausdance (Australian Capital Territory); CNRS – Centre National de la Recherche Scientifique; CSIRO – Commonwealth Scientific and Industrial Research Organisation; DAP - Data Acquisition and Processing; ES – Earth Sciences; FA – Faculty of Arts; GSM – Geophysical Survey and Mapping; IMAS – Institute for Marine and Antarctic Studies; IUEM – Institut Universitaire Européen de la Mer; LOMIC – Laboratoire d'Océanographie Microbienne; MNF - Marine National Facility; SA – School of Art; SIO – Scripps Institution of Oceanography; SIT – Seagoing Instrumentation Team; SPS – School of Physical Sciences; UBO - Université de Bretagne Occidentale; UCSD – University of California, San Diego; UNSW – University of New South Wales; UPMC - Université Pierre et Marie Curie; UTAS - University of Tasmania

Marine Crew

Name	Role
Michael Watson	Master
Roderick Quinn	Chief Mate
Brendan Eakin	Second Mate
Thomas Watson	Third Mate
Gennadiy Gervasiev	Chief Engineer
Sam Benson	First Engineer
Ian McDonald	Second Engineer
Damian Wright	Third Engineer
Shane Kromcamp	Electrical Engineer
Keith Shepherd	Chief Cook
Matt Gardiner	Cook
Cassandra Rowse	1/Steward
Emma Lade	1/Steward
Jonathan Lumb	Chief Integrated Rating
Dean Hingston	Integrated Rating
Darren Capon	Integrated Rating
Murray Lord	Integrated Rating
Matthew McNeill	Integrated Rating
Kel Lewis	Integrated Rating
Ryan Drennan	Integrated Rating

Acknowledgements

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Signature

Your name	Millard F Coffin
Title	Chief Scientist
Signature	
Date:	16 June 2016

Additional Figures

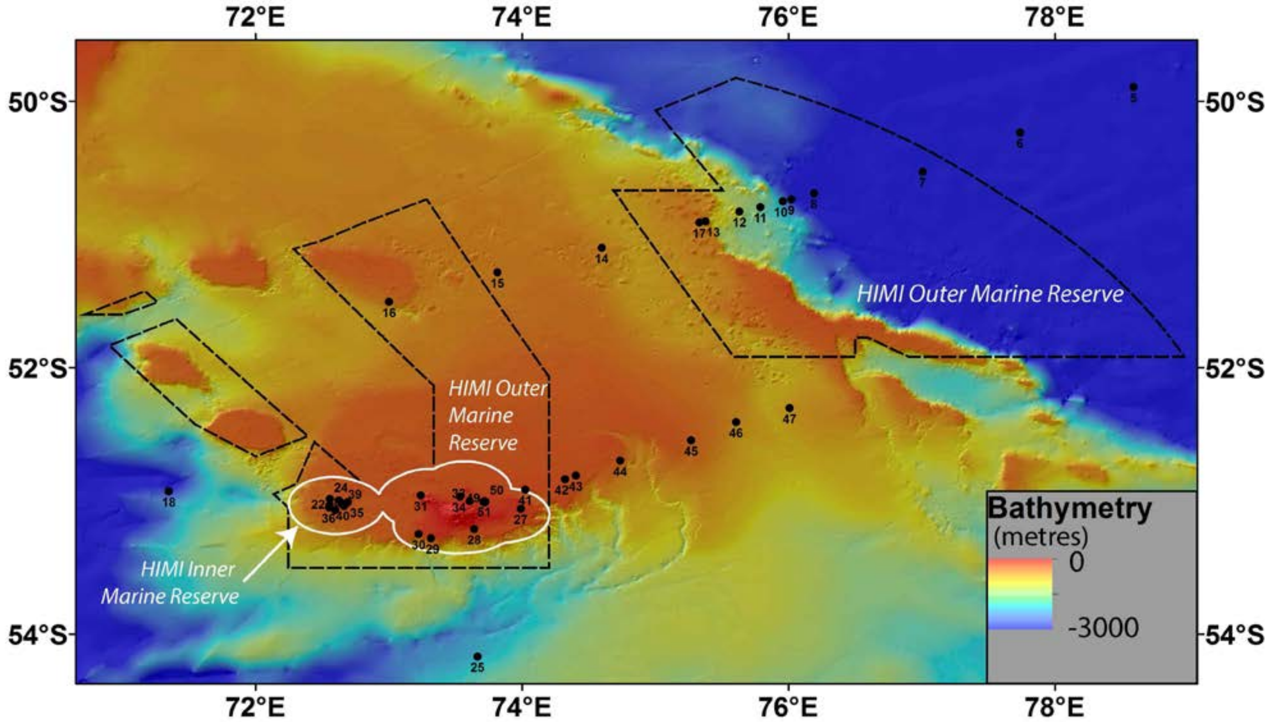

Figure 1. Stations in the Central Kerguelen Plateau study area. See Figures 2, 3, and 4 for enlargements of the McDonald Islands and Heard Island regions.

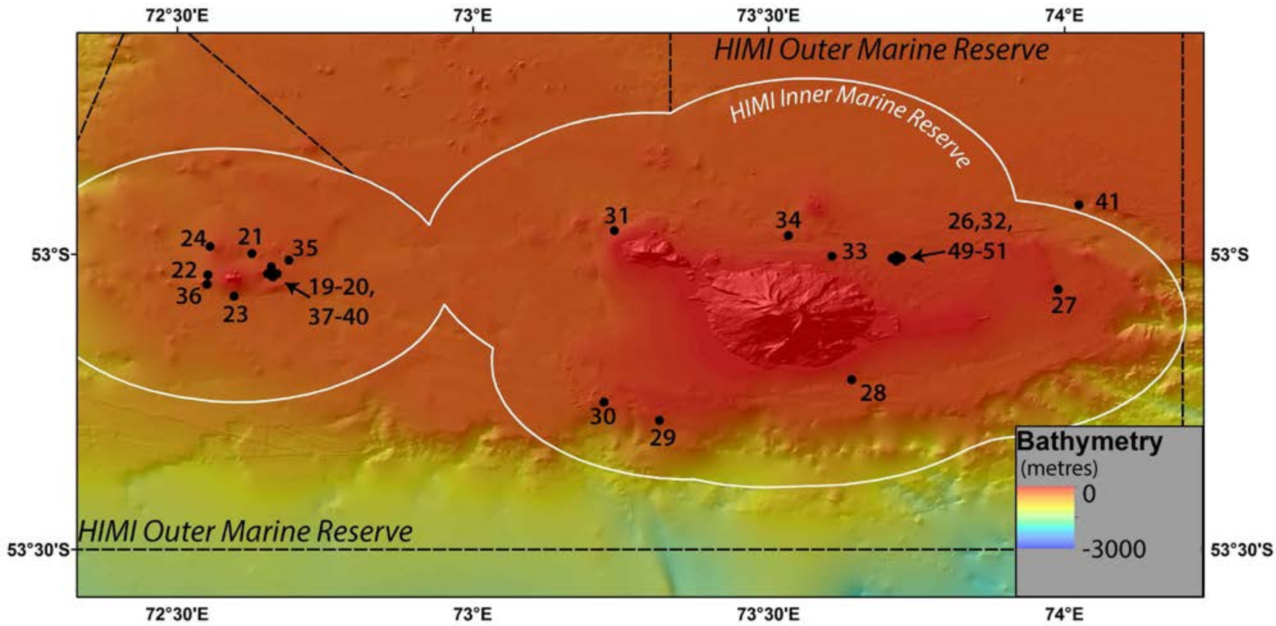

Figure 2. Stations in the Heard and McDonald Island regions. See Figures 3 and 4 for enlargements of the McDonald Islands and Heard Island study areas, respectively.

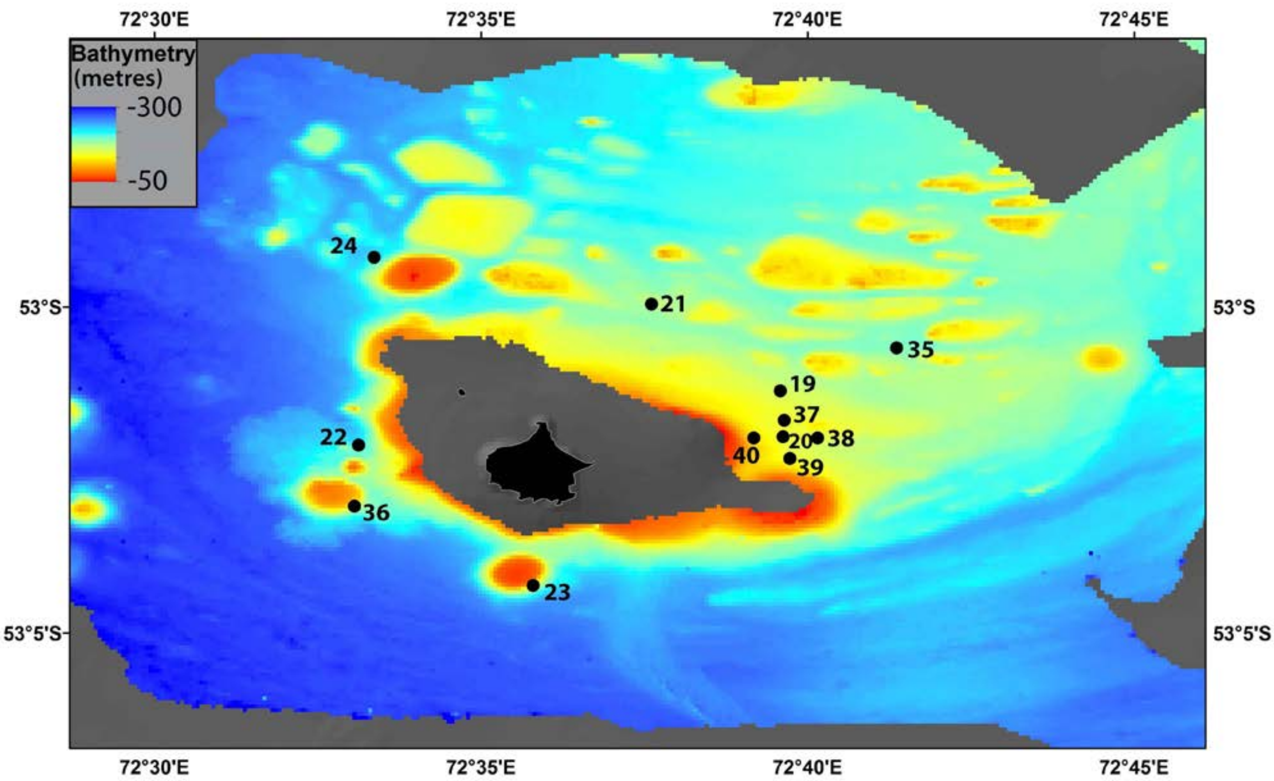

Figure 3. Stations around the McDonald Islands, superimposed on new IN2016_V01 bathymetry (colour) and existing bathymetry (grayscale).

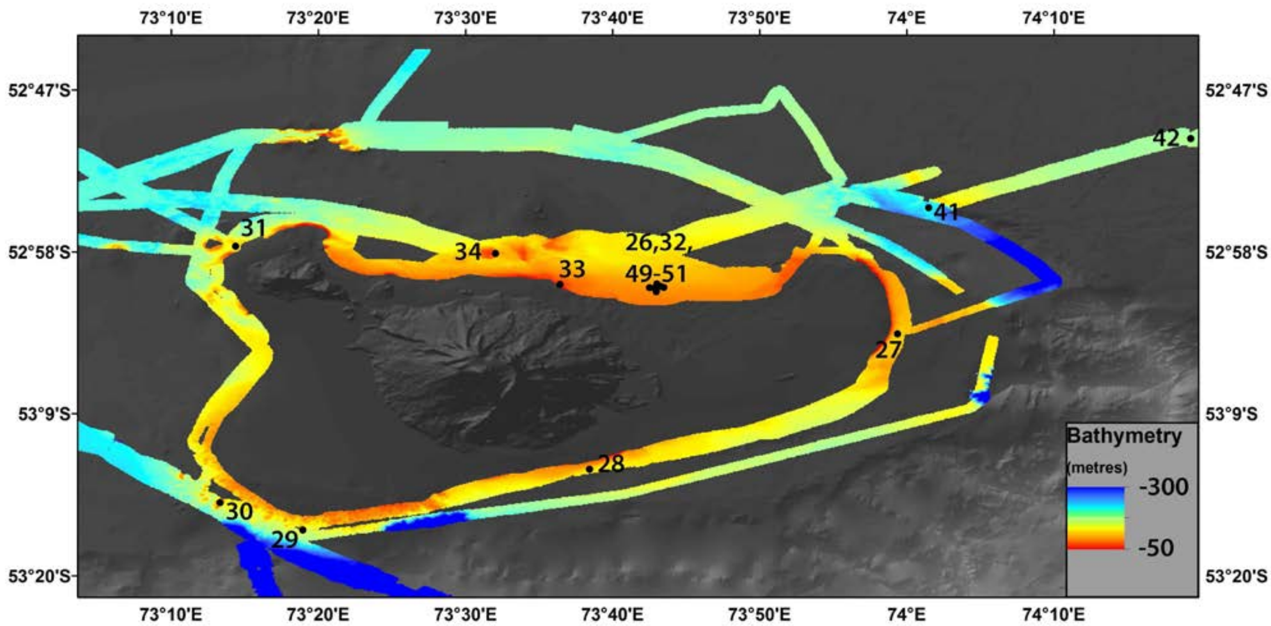

Figure 4. Stations around Heard Island, superimposed on new IN2016_V01 bathymetry (colour) and existing bathymetry (grayscale).

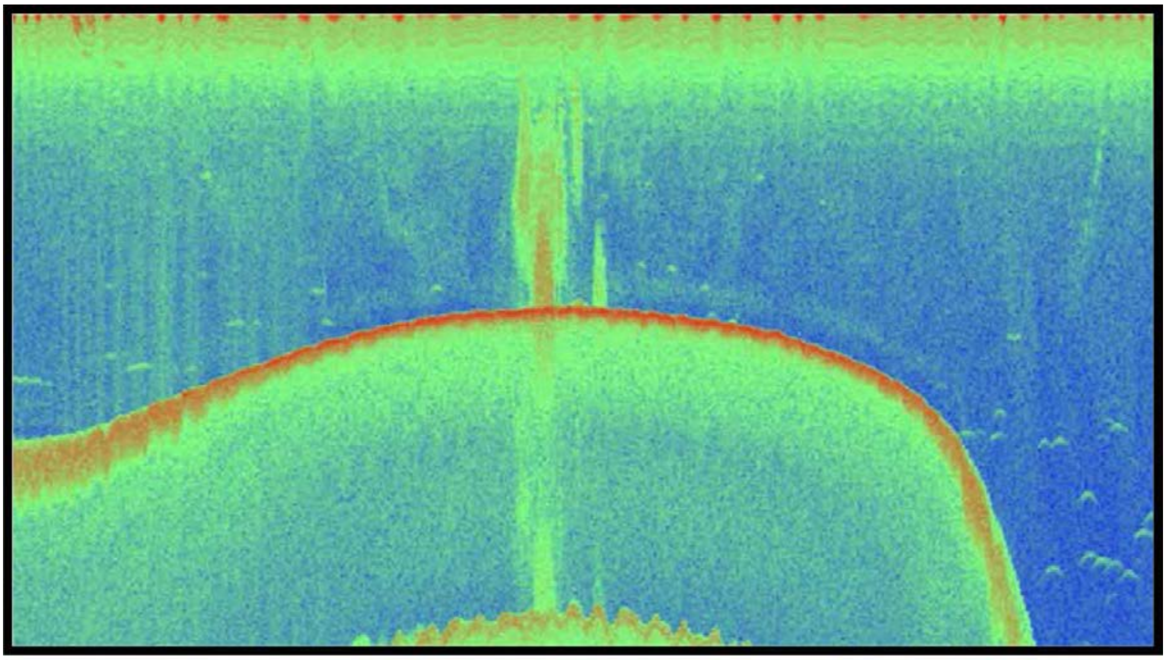

Figure 5. Acoustic plumes emanating from the crest of the sea knoll directly south of the McDonald Islands (see Figure 3; station 23 was undertaken on this feature), as imaged on raw EK60 split-beam echosounder data. Water depth at the crest is ~78 m; the major acoustic plume extends ~70 m into the water column, nearly reaching the sea surface.

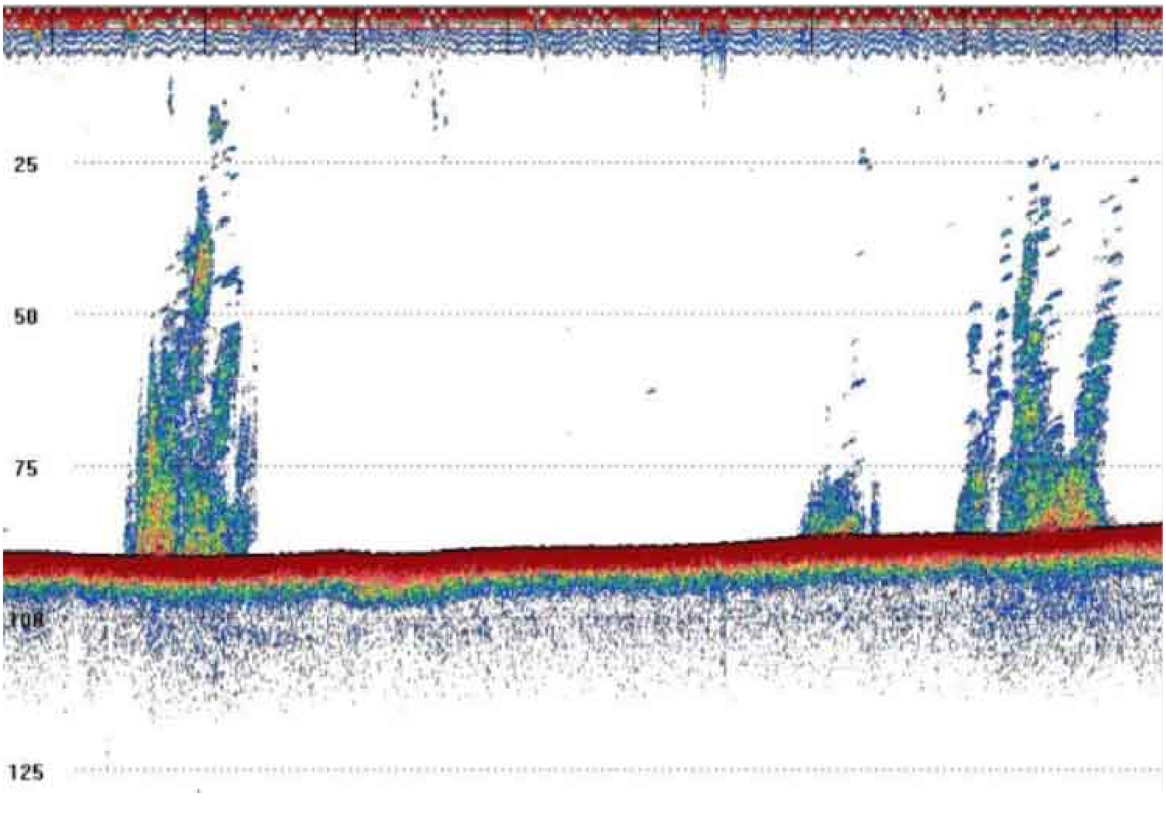

Figure 6. Acoustic plumes emanating from relatively flat seafloor northeast of Heard Island (see Figure 4; stations 26, 32, and 48-51 were undertaken in this acoustic plume field), as imaged on raw EK60 split-beam echosounder data. Water depths average ~85 m; the acoustic plumes extend as much as ~70 m into the water column, nearly reaching the sea surface.

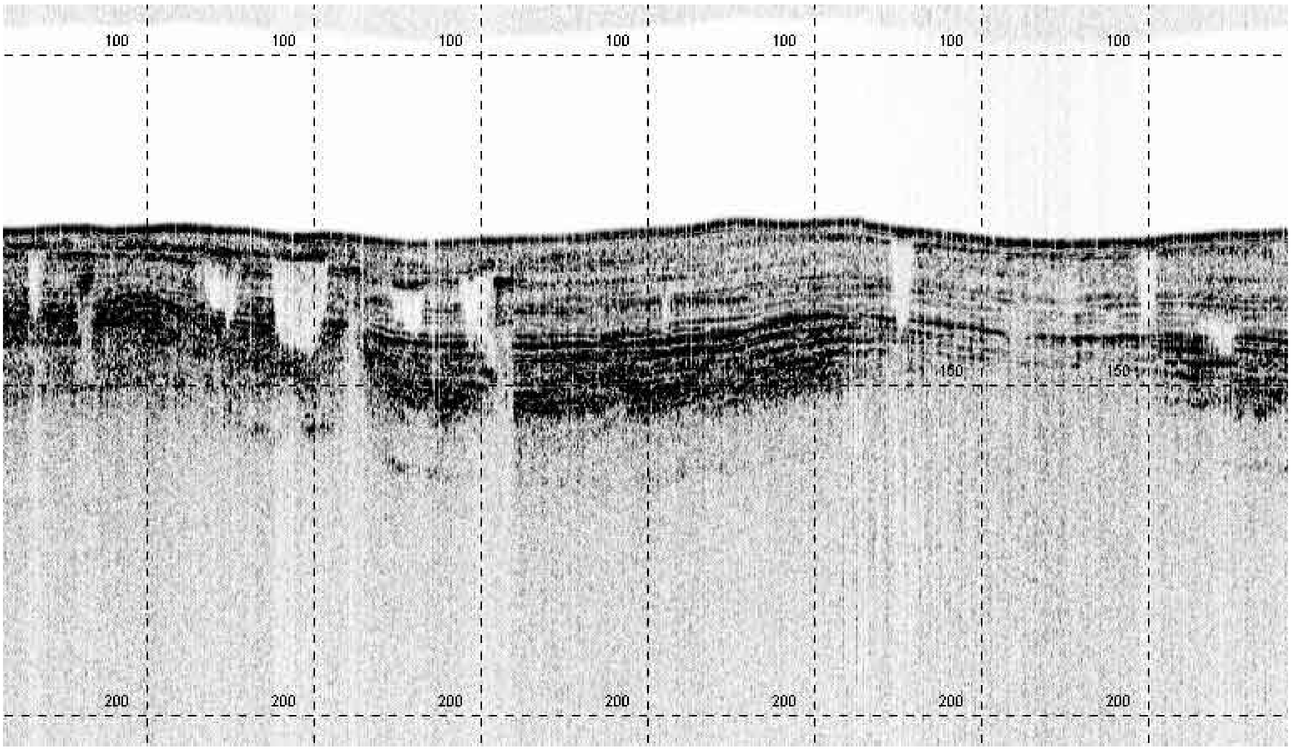

Figure 7. Acoustic blank zones underlying relatively flat seafloor northeast of Heard Island (see Figure 4; stations 26, 32, and 48-51 were undertaken in this area, which is an acoustic plume field), as imaged on raw SBP120 data. Water depth averages ~85 m.

Figure 8. Bubbles emanating from relatively flat seafloor in an acoustic plume field northeast of Heard Island (see Figures 4, 6, and 7; stations 26, 32, and 48-51 were undertaken in this area). Water depth is ~85 m. Laser dots (upper left quadrant) are 10 cm apart.

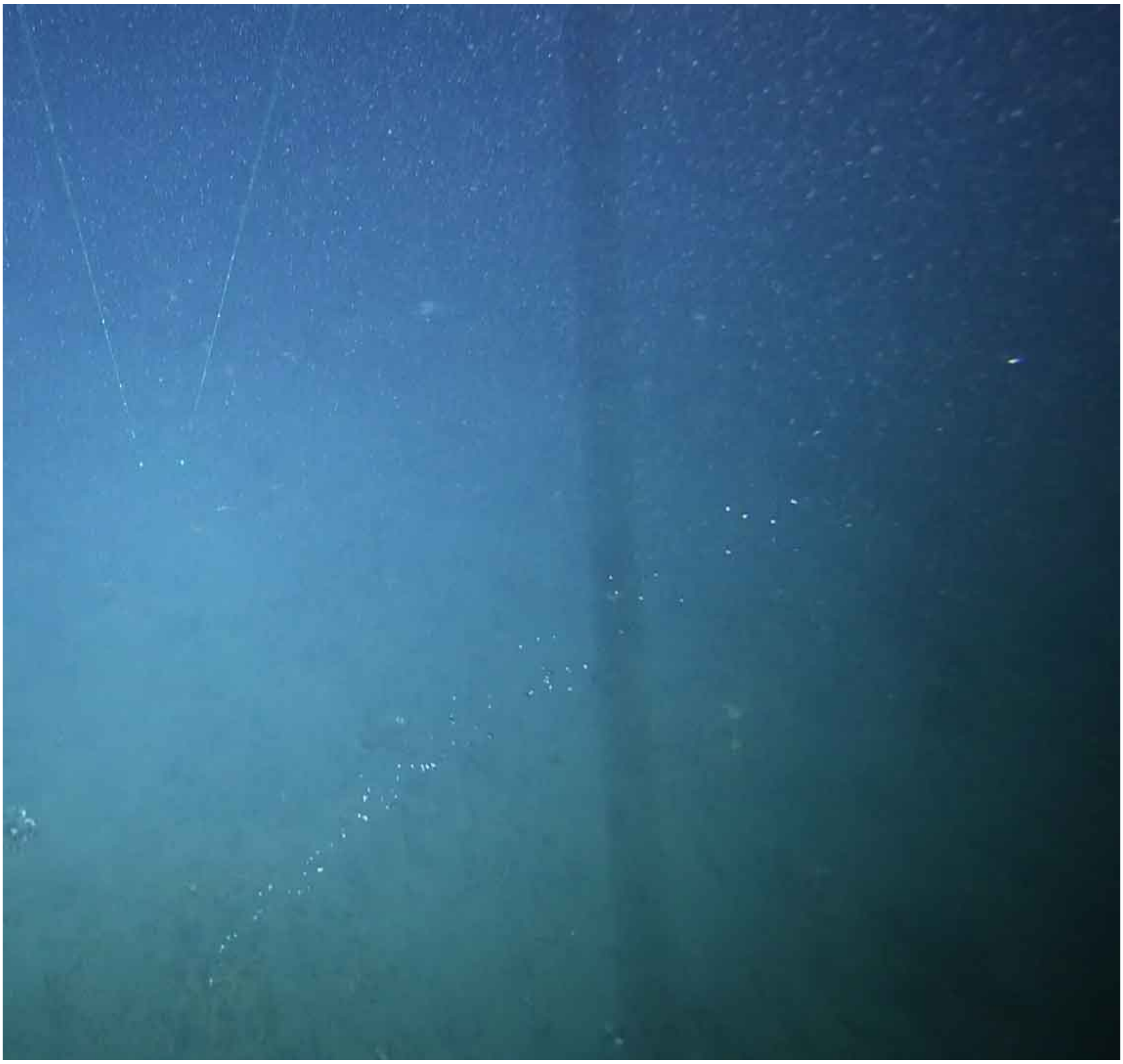

Figure 9. Stream of bubbles in the water column in an acoustic plume field northeast of Heard Island (see Figures 4, 6, and 7; stations 26, 32, and 48-51 were undertaken in this area). Water depth is ~85 m. Laser dots (upper left quadrant) are 10 cm apart.

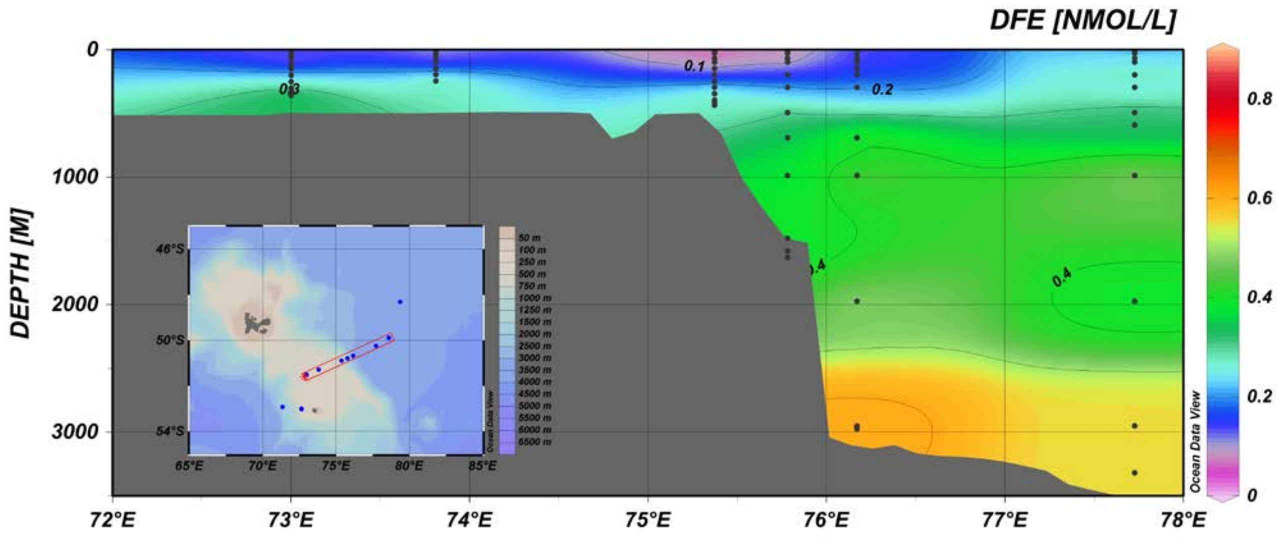

Figure 10. Distribution of dissolved iron along the HEOBI ‘central’ east-west transect (DWBC/KEOPS ‘B’-line) from deep waters onto the central Kerguelen plateau.

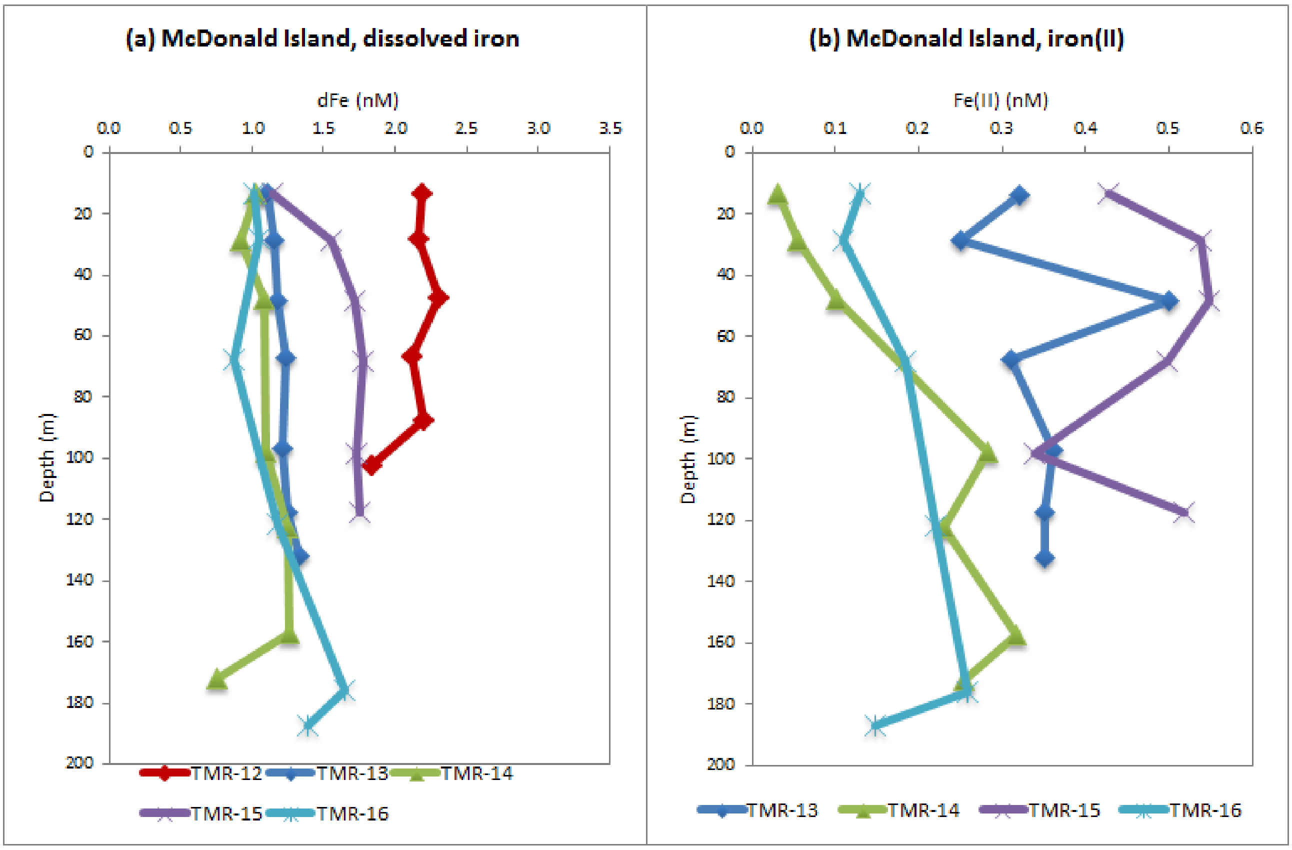

Figure 11. Vertical profiles of (a) dissolved iron (b) and iron(II) at five stations proximal to the McDonald Islands. See Figure 3 for locations; TMR-12 = Station 20, TMR-13 = Station 21, TMR-14 = Station 22, TMR-15 = Station 23, and TMR-16 = Station 24.

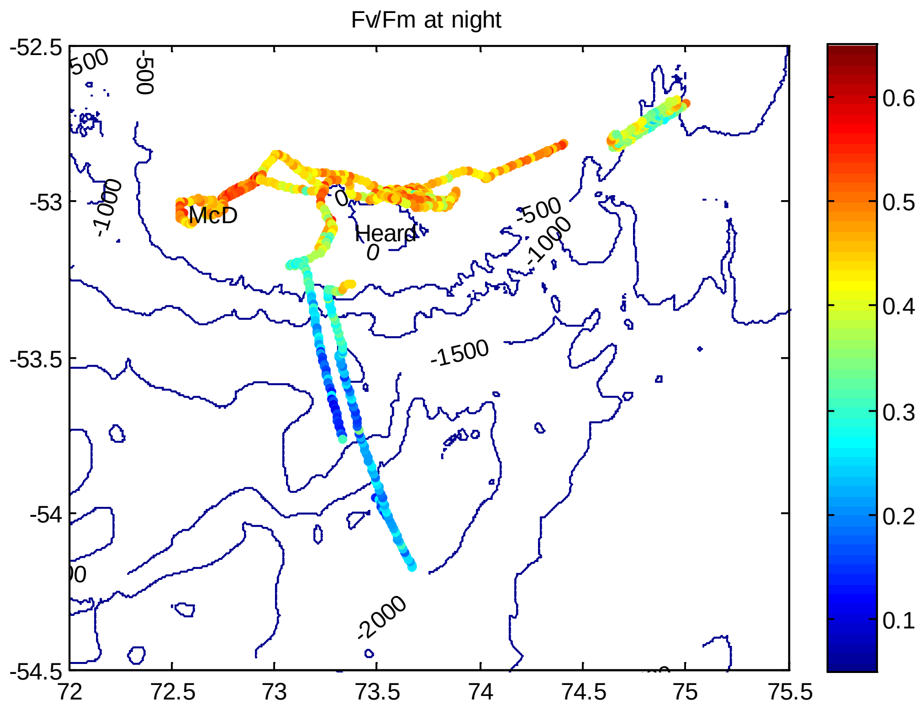

Figure 12. Normalized variable fluorescence (Fv/Fm) from the underway FIRe instrument. Only night-time data are shown, thus eliminating the diel cycle from solar induced fluorescence quenching (later analysis may allow daytime data to be added using a mean solar cycle correction and ship radiation observations). Low values in blue along the southward ship tracks to and from the station 25 (southern reference site) are typical of iron-poor HNLC Southern Ocean background values. High values in red over the Central Kerguelen Plateau north of Heard Island and especially around the McDonald Islands – but not Gunnari Ridge to the east of Heard Island – indicate much greater (near maximal) photosynthetic function by phytoplankton.

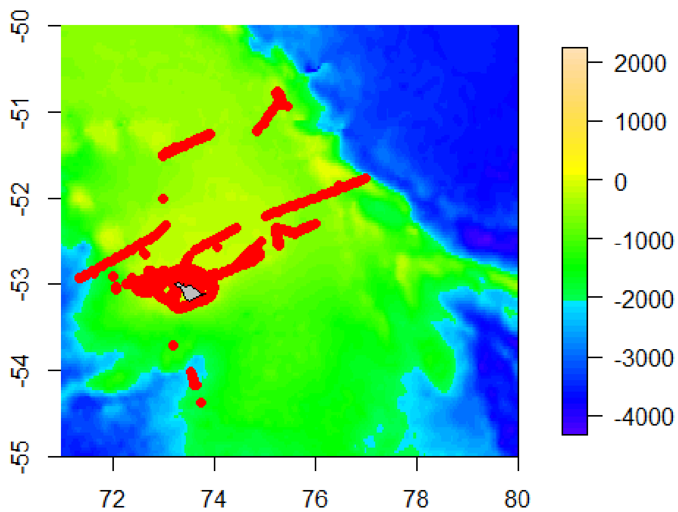

Figure 13. Locations of seabird transect counts (red) over the Central Kerguelen Plateau.

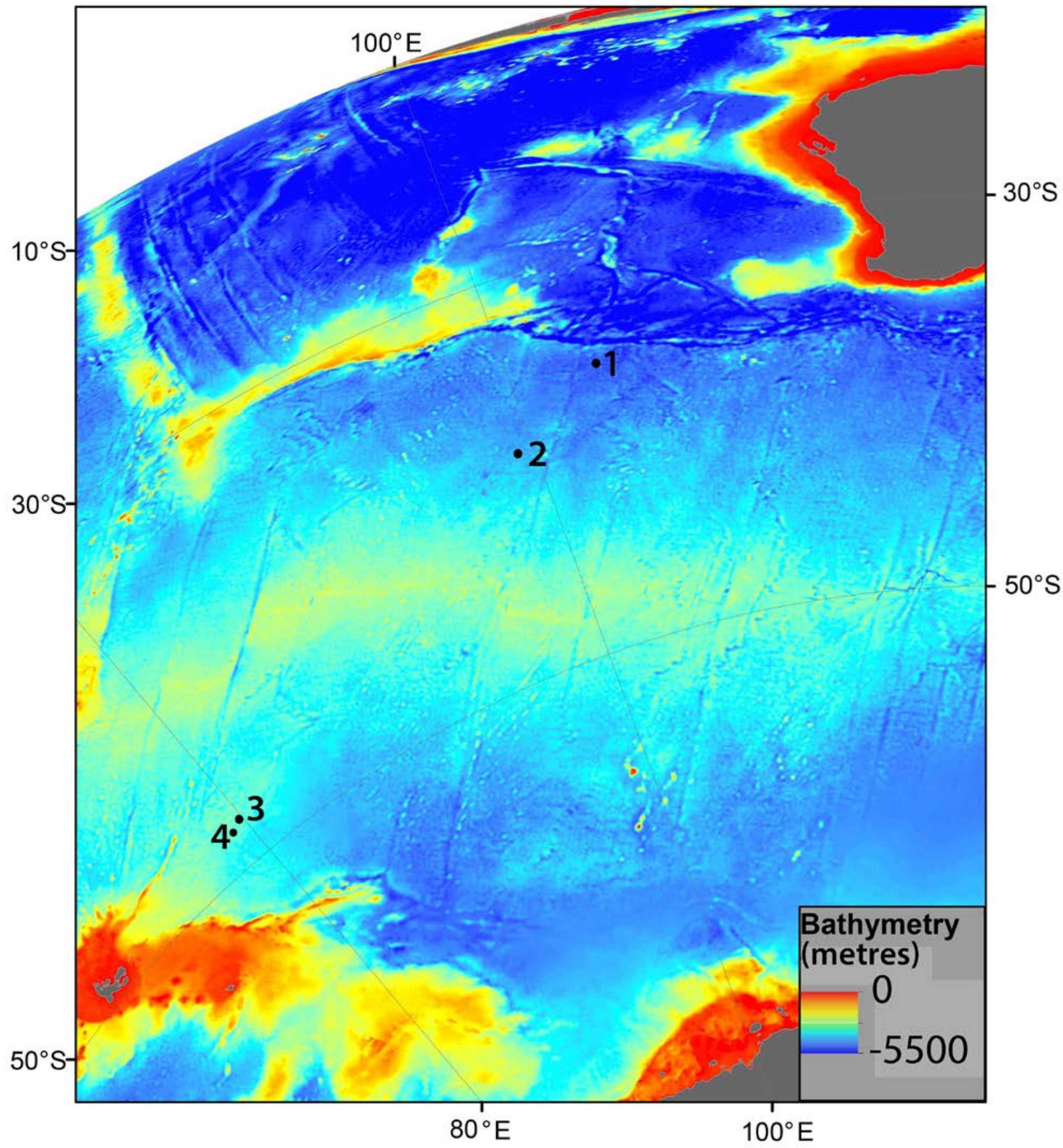

Figure 14. Stations along the transit from Fremantle to the Kerguelen Plateau. Equipment tests were undertaken in two eddies (1, 2) and across the Polar Front (3, 4).

Appendices

Appendix 1 Station Positions

Station locations are shown in Figures 1-4 and 14.

CODES KEY:

A	ARGO float
AI	Float
BP	BO-Pak
CTD	Conductivity/Temperature/Salinity
DR	Drifter
EIMS	Equilabrator inlet mass spectrometry
HD	Rock Dredge
ISP	In-Situ Pumps
SMG	Smith McIntyre Grab
SOC	SOCCOM float
T	Triaxus
TC	Towed Camera
TMR	Trace Metal Rosette
XBT	Expendable Bathythermograph

STATIONS:

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
transit	Air chemistry	8/01/16	10:00:00	0.0000	0.00000
transit	EIMS	10/01/16	1:00:00	0.0000	0.00000
transit	test	10/01/16	5:20:00	106.2317	35.62833
transit	test	10/01/16	6:16:00	106.2317	35.62833
transit	DR-01	10/01/16	10:34:00	99.4072	39.48983
transit	XBT-01	10/01/16	14:26:00	104.7335	36.06917
Site 1	CTD-01	10/01/16	19:59:00	103.6429	36.37662
Site 1	CTD 01	10/01/16	22:10:00	103.6461	36.36295
Site 1	TMR-01	10/01/16	22:30:00	103.6461	36.36295
Site 1	TMR-01	10/01/16	22:52:00	106.2317	35.62833
Site 1	BP-01	10/01/16	23:34:00	106.2317	35.62833
Site 1	BP-01	10/01/16	23:54:00	106.2317	35.62833
transit	AI-01	11/01/16	0:48:00	103.6353	36.35683
transit	DR-02	11/01/16	5:47:09	103.6416	36.35642
Site 2	BP-02	11/01/16	7:20:00	99.3800	39.49833
Site 2	BP-02	11/01/16	8:00:00	99.3800	39.49833

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
transit	XBT-02	11/01/16	11:48:00	104.7335	37.39300
Site 2	CTD-02	12/01/16	8:09:00	99.3893	39.49207
Site 2	AI-02	12/01/16	10:18:00	99.4131	39.48365
Site 2	CTD-02	12/01/16	10:23:00	99.3893	39.65053
Site 2	ISP-01	12/01/16	11:20:00	99.3893	39.65053
Site 2	ISP-01	12/01/16	13:06:00	99.4100	39.48833
transit	T-01	12/01/16	13:36:00	99.3800	39.48833
Site 2	T-01	12/01/16	13:36:00	99.3800	39.49833
transit	XBT-03	12/01/16	22:35:00	97.5467	40.35833
transit	T-02	13/01/16	8:10:00	0.0000	0.00000
transit	T-02	13/01/16	8:30:00	0.0000	0.00000
transit	SOC-01	13/01/16	8:44:05	99.4097	39.48938
transit	T-03	14/01/16	8:49:02	91.3567	43.16000
transit	T-03	14/01/16	11:24:06	91.3567	43.16000
transit	EIMS	15/01/16	3:30:00	0.0000	0.00000
transit	DR-03	15/01/16	3:37:00	87.4823	44.86333
transit	A-04	15/01/16	5:12:14	87.5241	44.84506
transit	A-05	16/01/16	7:57:01	82.1577	47.11382
transit	XBT-04	16/01/16	13:16:00	81.1010	47.54967
Site 3	CTD-03	16/01/16	18:15:00	80.0000	48.00000
Site 4	CTD-04	16/01/16	22:35:30	79.3403	48.27967
Site 4	CTD-04	17/01/16	0:46:12	79.3665	48.27917
Site 4	BP-03	17/01/16	0:55:00	79.3665	48.27917
Site 4	BP-03	17/01/16	1:09:17	79.3706	48.27867
Site 4	TMR-02	17/01/16	1:35:42	79.3738	48.31117
Site 4	TMR-02	17/01/16	3:05:27	79.3902	48.27915
Site 4	ISP-02	17/01/16	3:45:00	79.3978	48.28020
Site 4	ISP-02	17/01/16	4:08:00	79.3994	48.28088
Site 4	ISP-02	17/01/16	4:21:00	79.4052	48.28220
Site 4	ISP-02	17/01/16	4:26:00	79.4078	48.28345
Site 4	ISP-02	17/01/16	4:32:00	79.4090	48.28410
Site 4	ISP-02	17/01/16	4:36:00	79.4103	48.28480
Site 4	ISP-02	17/01/16	4:41:00	79.4110	48.28533
Site 4	ISP-02	17/01/16	4:45:00	79.4122	48.28615
Site 4	SOC-02	17/01/16	7:16:47	79.4468	48.29350
Site 4	ISP-02	17/01/16	7:17:08	79.4393	48.29250
Site 4	ISP-02	17/01/16	7:18:38	79.4395	48.29250
Site 4	ISP-02	17/01/16	7:20:48	79.4400	48.29250
Site 4	ISP-02	17/01/16	7:23:42	79.4403	48.29267
Site 4	ISP-02	17/01/16	7:25:00	79.4410	48.29267
Site 4	ISP-02	17/01/16	7:26:31	79.4408	48.29250
Site 4	ISP-02	17/01/16	7:27:08	79.4408	48.29250
Site 4	ISP-02	17/01/16	7:50:32	79.4453	48.29333
Site 4	DR-04	17/01/16	7:58:41	79.4472	48.29017

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 4	T-04	17/01/16	8:16:00	79.4467	48.29333
Transit	T-04	17/01/16	22:36:00	78.5755	49.90450
Site 5 / DWBC 1 / HIPPIES 1	CTD-05	17/01/16	23:09:37	78.5764	49.90313
Site 5 / DWBC 1 / HIPPIES 1	CTD-05	17/01/16	23:38:58	78.5815	49.90275
Site 5 / DWBC 1 / HIPPIES 1	CTD-05	17/01/16	23:42:26	78.5819	49.90274
Site 5 / DWBC 1 / HIPPIES 1	BP-04	17/01/16	23:57:00	78.5836	49.90262
Site 5 / DWBC 1 / HIPPIES 1	BP-04	18/01/16	0:20:35	78.5878	49.90143
Site 5 / DWBC 1 / HIPPIES 1	CTD-06	18/01/16	0:38:59	78.5890	49.89950
Site 5 / DWBC 1 / HIPPIES 1	CTD-06	18/01/16	3:35:15	78.5992	49.89404
Site 5 / DWBC 1 / HIPPIES 1	CTD-06	18/01/16	3:38:00	78.5992	49.89409
Site 5 / DWBC 1 / HIPPIES 1	TMR-03	18/01/16	4:03:00	78.5966	49.88913
Site 5 / DWBC 1 / HIPPIES 1	TMR-03	18/01/16	6:38:00	78.6150	49.87315
Site 5 / DWBC 1 / HIPPIES 1	SOC-03	18/01/16	6:52:00	78.6182	49.86985
Site 5 / DWBC 1 / HIPPIES 1	A-06	18/01/16	6:57:01	78.6189	49.86796
Site 6 / DWBC 2	BP-05	18/01/16	11:59:13	77.7662	50.22300
Site 6 / DWBC 2	BP-05	18/01/16	12:28:00	78.6320	49.86983
Site 6 / DWBC 2	CTD-07	18/01/16	12:55:33	77.7533	50.22983
transit	EIMS	18/01/16	14:39:00	0.0000	0.00000
Site 6 / DWBC 2	CTD-07	18/01/16	15:55:03	77.7288	50.24000
Site 6 / DWBC 2	TMR-04	18/01/16	16:14:38	77.7268	50.24017
Site 6 / DWBC 2	TMR-04	18/01/16	18:49:18	77.7222	50.23333
Site 7 / DWBC 3 / KEOPS B11	BP-06	18/01/16	23:13:05	77.0010	50.49967
Site 7 / DWBC 3 / KEOPS B11	BP-06	18/01/16	23:39:46	77.0035	50.50783
Site 7 / DWBC 3 / KEOPS B11	CTD-08	18/01/16	23:55:00	77.0036	50.51188
Site 7 / DWBC 3 / KEOPS B11	CTD-08	19/01/16	2:55:00	77.0238	50.59233
Site 7 / DWBC 3 / KEOPS B11	CTD-08	19/01/16	2:57:50	77.0255	50.54367
Site 8 / DWBC 4 / KEOPS B09	BP-07	19/01/16	7:54:24	76.2000	50.69683
Site 8 / DWBC 4 / KEOPS B09	BP-07	19/01/16	8:22:46	76.2013	50.69467
Site 8 / DWBC 4 / KEOPS B09	CTD-09	19/01/16	8:35:12	76.2009	50.69450
Site 8 / DWBC 4 / KEOPS B09	CTD-09	19/01/16	11:11:29	76.1870	50.69100
Site 8 / DWBC 4 / KEOPS B09	TMR-05	19/01/16	11:27:59	76.1855	50.69117
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Site 9 / DWBC 5	BP-08	19/01/16	15:35:46	76.0245	50.74250
Site 9 / DWBC 5	BP-08	19/01/16	16:01:50	76.0227	50.73917
Site 9 / DWBC 5	CTD-10	19/01/16	16:14:52	76.0207	50.74050
Site 9 / DWBC 5	CTD-10	19/01/16	18:43:27	76.0135	50.72400
Site 10 / DWBC 6	BP-09	19/01/16	19:50:24	75.9573	50.75765
Site 10 / DWBC 6	BP-09	19/01/16	20:15:34	75.9565	50.75160
Site 10 / DWBC 6	CTD-11	19/01/16	20:33:00	75.9565	50.75080
Site 10 / DWBC 6	CTD-11	19/01/16	22:44:00	75.9586	50.73563
Site 10 / DWBC 6	CTD-11	19/01/16	22:46:33	75.9585	50.73512
Site 11 / DWBC 7 / KEOPS B08	BP-10	20/01/16	0:17:00	75.8005	50.79648
Site 11 / DWBC 7 / KEOPS B08	BP-10	20/01/16	0:44:42	75.7945	50.79370
Site 11 / DWBC 7 / KEOPS B08	CTD-12	20/01/16	0:58:00	75.7916	50.79165

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 11 / DWBC 7 / KEOPS B08	CTD-12	20/01/16	2:32:00	75.7820	50.78867
Site 11 / DWBC 7 / KEOPS B08	CTD-12	20/01/16	2:34:59	75.7820	50.78883
Site 11 / DWBC 7 / KEOPS B08	TMR-06	20/01/16	3:00:00	75.7817	50.79450
Site 11 / DWBC 7 / KEOPS B08	TMR-06	20/01/16	4:41:00	75.7773	50.78760
Site 12 / DWBC 08	BP-11	20/01/16	6:13:37	75.6373	50.83445
Site 12 / DWBC 08	BP-11	20/01/16	6:40:00	75.6369	50.82953
Site 12 / DWBC 08	CTD-13	20/01/16	6:55:43	75.6340	50.82733
Site 12 / DWBC 08	CTD-13	20/01/16	8:16:48	75.6153	50.81633
Site 13 / KEOPS B07	CTD-14	20/01/16	10:07:00	75.3777	50.89950
Site 13 / KEOPS B07	CTD-14	20/01/16	10:51:50	75.3792	50.89917
Site 13 / KEOPS B07	TMR-07	20/01/16	11:07:39	75.3732	50.89983
Site 13 / KEOPS B07	TMR-07	20/01/16	11:39:26	75.3665	50.90533
Site 14 / KEOPS B05	BP-12	20/01/16	17:38:21	74.5973	51.10150
Site 14 / KEOPS B05	BP-12	20/01/16	18:03:16	74.5970	51.10083
Site 14 / KEOPS B05	CTD-15	20/01/16	18:17:49	74.5997	51.10067
Site 14 / KEOPS B05	CTD-15	20/01/16	19:06:54	74.5940	51.09817
Site 14 / KEOPS B05	CTD-15	20/01/16	19:11:47	74.5937	51.09817
Site 14 / KEOPS B05	TMR-08	20/01/16	19:23:00	74.5978	51.09667
Site 14 / KEOPS B05	TMR-08	20/01/16	19:58:25	74.5942	51.09750
Site 15 / KEOPS B03	CTD-16	21/01/16	0:49:00	73.8027	51.28617
Site 15 / KEOPS B03	CTD-16	21/01/16	1:31:32	73.8095	51.28717
Site 15 / KEOPS B03	CTD-16	21/01/16	1:40:54	73.8102	51.28700
Site 15 / KEOPS B03	TMR-09	21/01/16	1:51:29	73.8112	51.28717
Site 15 / KEOPS B03	TMR-09	21/01/16	2:22:37	73.8142	51.28633
Site 15 / KEOPS B03	ISP-03	21/01/16	2:38:10	73.8137	51.28583
Site 15 / KEOPS B03	ISP-03	21/01/16	2:43:41	73.8130	51.28600
Site 15 / KEOPS B03	ISP-03	21/01/16	2:49:30	73.8137	51.28583
Site 15 / KEOPS B03	ISP-03	21/01/16	2:54:30	73.8138	51.28567
Site 15 / KEOPS B03	ISP-03	21/01/16	2:59:00	73.8152	51.28550
Site 15 / KEOPS B03	ISP-03	21/01/16	3:03:00	73.8158	51.28517
Site 15 / KEOPS B03	ISP-03	21/01/16	5:40:00	73.8152	51.28383
Site 15 / KEOPS B03	ISP-03	21/01/16	5:45:00	73.8150	51.28383
Site 15 / KEOPS B03	ISP-03	21/01/16	5:48:00	74.8133	51.28383
Site 15 / KEOPS B03	ISP-03	21/01/16	5:52:00	73.8000	51.28383
Site 15 / KEOPS B03	ISP-03	21/01/16	5:55:17	73.8152	51.28383
Site 15 / KEOPS B03	ISP-03	21/01/16	6:06:00	73.8158	51.28383
Site 15 / KEOPS B03	BP-13	21/01/16	6:14:39	73.8187	51.28350
Site 15 / KEOPS B03	BP-13	21/01/16	6:39:03	73.8193	51.31583
Site 16 / KEOPS B01	BP-14	21/01/16	11:27:06	73.0013	51.50117
Site 16 / KEOPS B01	BP-14	21/01/16	11:51:51	73.0000	51.50300
Site 16 / KEOPS B01	CTD-17	21/01/16	12:02:53	73.0015	51.50417
Site 16 / KEOPS B01	CTD-17	21/01/16	12:54:51	73.0005	51.50650
Site 16 / KEOPS B01	TMR-10	21/01/16	13:12:13	72.9992	51.50667
Site 16 / KEOPS B01	TMR-10	21/01/16	13:40:11	72.9987	51.50850

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 17	TC-01	22/01/16	3:14:00	72.9992	50.88983
Site 17	TC-01	22/01/16	3:20:00	72.9992	50.88983
Site 17	TC-02	22/01/16	3:34:00	72.9992	50.88983
Site 17	TC-02	22/01/16	8:47:00	72.9992	50.88983
Site 17	HD1	22/01/16	9:55:03	75.3398	50.92317
Site 17	HD-01	22/01/16	10:10:53	75.3328	50.91517
Site 17	HD-01	22/01/16	10:28:52	75.3268	50.90850
Site 17	HD-01	22/01/16	10:39:15	75.3232	50.90467
Site 17	HD-01	22/01/16	10:55:53	75.3187	50.89783
Site 18	BP-15	23/01/16	7:05:19	71.3737	52.92667
Site 18	BP-15	23/01/16	7:31:08	71.3722	52.92667
Site 18	CTD-18	23/01/16	7:44:08	71.3710	52.92667
Site 18	CTD-18	23/01/16	10:06:25	71.3617	52.92700
Site 18	TMR-11	23/01/16	10:53:13	71.3567	52.92800
Site 18	TMR-11	23/01/16	12:59:39	71.3433	52.93017
Site 18	ISP-04	23/01/16	13:25:08	71.3333	52.93067
Site 18	ISP-04	23/01/16	13:40:41	71.3422	52.93017
Site 18	ISP-04	23/01/16	13:50:21	71.3427	52.93017
transit	EIMS	23/01/16	13:52:00	0.0000	0.00000
Site 18	ISP-04	23/01/16	14:00:30	71.3425	52.92967
Site 18	ISP-04	23/01/16	14:06:08	71.3420	52.92983
Site 18	ISP-04	23/01/16	14:11:02	71.3417	52.93000
Site 18	ISP-04	23/01/16	14:15:39	71.3420	52.93000
Site 18	ISP-04	23/01/16	14:19:57	71.3427	52.93017
Site 18	ISP-04	23/01/16	16:52:41	71.3372	52.92800
Site 18	ISP-04	23/01/16	16:55:16	71.3377	52.92850
Site 18	ISP-04	23/01/16	16:57:23	71.3368	52.92867
Site 18	ISP-04	23/01/16	17:00:17	71.3360	52.92850
Site 18	ISP-04	23/01/16	17:03:22	71.3357	52.92850
Site 18	ISP-04	23/01/16	17:11:05	71.3348	52.92850
Site 18	ISP-04	23/01/16	17:18:25	71.3352	52.92933
Site 18	ISP-04	23/01/16	17:30:12	71.3355	52.92967
transit	EIMS	26/01/16	7:20:00	0.0000	0.00000
Site 19	TC-03	27/01/16	6:45:14	72.6675	53.02767
Site 19	TC-03	27/01/16	7:03:57	72.6583	53.01950
Site 20	CTD-19	27/01/16	8:07:18	72.6607	53.03283
Site 20	CTD-19	27/01/16	8:27:24	72.6598	53.03250
Site 20	CTD-20	27/01/16	8:28:31	72.6597	53.03250
Site 20	CTD-20	27/01/16	8:47:55	72.6587	53.03250
Site 20	TMR-12	28/01/16	6:13:21	72.6604	53.03312
Site 20	TMR-12	28/01/16	6:28:17	72.6595	53.03287
Site 20	ISP-05	28/01/16	6:50:12	72.6596	53.03262
Site 20	ISP-05	28/01/16	6:53:40	72.6592	53.03283
Site 20	ISP-05	28/01/16	7:02:52	72.6600	53.03300

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 20	ISP-05	28/01/16	7:07:38	72.6602	53.03300
Site 20	ISP-05	28/01/16	8:38:42	72.6592	53.03350
Site 20	ISP-05	28/01/16	8:40:25	72.6592	53.03367
Site 20	ISP-05	28/01/16	8:42:41	73.6590	53.03367
Site 20	ISP-05	28/01/16	8:45:16	72.6592	53.03367
Site 20	SMG-01	28/01/16	9:01:00	72.6595	53.03333
Site 20	SMG-01	28/01/16	9:10:05	72.6595	53.03333
Site 21	CTD-21	28/01/16	11:23:53	72.6333	52.99967
Site 21	CTD-21	28/01/16	11:47:06	72.6260	52.99867
Site 21	BP-16	28/01/16	12:23:14	72.6210	52.99800
Site 21	BP-16	28/01/16	12:41:16	72.6143	52.99967
transit	EIMS	28/01/16	13:13:00	0.0000	0.00000
Site 21	TMR-13	28/01/16	13:13:40	72.6348	52.99867
Site 21	TMR-13	28/01/16	13:38:47	72.6323	52.99983
Site 22	CTD-22	29/01/16	0:16:07	72.5521	53.03520
Site 22	CTD-22	29/01/16	0:41:45	72.5522	53.03505
Site 22	CTD-22	29/01/16	0:45:00	72.5522	53.03500
Site 22	TMR-14	29/01/16	1:08:24	72.5518	53.03485
Site 22	TMR-14	29/01/16	1:29:23	72.5522	53.03515
Site 22	ISP-06	29/01/16	1:47:52	72.5522	53.03513
Site 22	ISP-06	29/01/16	1:51:50	72.5534	53.03548
Site 22	ISP-06	29/01/16	1:56:48	72.5525	53.03520
Site 22	ISP-06	29/01/16	2:02:43	72.5519	53.03513
Site 22	ISP-06	29/01/16	3:22:39	72.5522	53.03548
Site 22	ISP-06	29/01/16	3:25:41	72.5520	53.03562
Site 22	ISP-06	29/01/16	3:29:21	72.5516	53.03563
Site 22	ISP-06	29/01/16	3:32:20	72.5511	53.03550
Site 22	SMG-02	29/01/16	4:01:34	72.5517	53.03550
Site 22	SMG-02	29/01/16	4:12:18	72.5522	53.03583
Site 23	BP-16	29/01/16	5:57:13	72.5926	53.07218
Site 23	BP-16	29/01/16	6:10:53	72.5930	53.07215
Site 23	CTD-23	29/01/16	6:29:51	72.5930	53.07245
Site 23	CTD-23	29/01/16	6:45:27	72.5932	53.07258
Site 23	CTD-23	29/01/16	6:46:56	72.5932	53.07262
Site 23	TMR-15	29/01/16	6:59:40	72.5933	53.07300
Site 23	TMR-15	29/01/16	7:15:57	72.5930	53.07267
Site 23	TC-04	29/01/16	8:46:40	72.5903	53.07233
Site 23	TC-04	29/01/16	11:21:53	72.6130	53.07117
Site 24	CTD-24	29/01/16	12:58:52	72.5560	52.98167
Site 24	CTD-24	29/01/16	13:31:09	72.5552	52.98467
Site 24	BP-17	29/01/16	13:46:47	72.5535	52.98183
Site 24	BP-17	29/01/16	14:11:19	72.5458	52.98650
Site 24	TMR-16	29/01/16	14:37:21	72.5532	52.98250
Site 24	TMR-16	29/01/16	15:01:11	72.5440	52.98750

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 24	HD-02	29/01/16	15:58:20	72.5690	52.99900
Site 24	HD-02	29/01/16	16:55:10	72.5712	52.99283
transit	pCO2	30/01/16	1:33:00	0.0000	0.00000
transit	T-05	31/01/16	14:38:04	73.2805	53.28317
transit	T-05	31/01/16	16:53:53	73.3213	53.48733
Site 25	CTD-25	31/01/16	23:23:11	73.6677	54.16685
Site 25	CTD-25	1/02/16	1:07:30	73.6645	54.16718
Site 25	CTD-25	1/02/16	1:09:33	73.6649	54.16738
Site 25	TMR-17	1/02/16	1:34:28	73.6682	54.16768
Site 25	TMR-17	1/02/16	1:54:48	73.6673	54.16750
Site 25	BP-18	1/02/16	2:14:12	73.6667	54.16717
Site 25	BP-18	1/02/16	2:28:53	73.6662	54.16723
Site 25	ISP-07	1/02/16	2:43:46	73.6673	54.16700
Site 25	ISP-07	1/02/16	2:55:04	73.6669	54.16715
Site 25	ISP-07	1/02/16	3:08:32	73.6674	54.16718
Site 25	ISP-07	1/02/16	3:26:14	73.6668	54.16755
Site 25	ISP-07	1/02/16	3:30:47	73.6672	54.16742
Site 25	ISP-07	1/02/16	3:34:52	73.6674	54.16749
Site 25	ISP-07	1/02/16	3:38:36	73.6678	54.16753
Site 25	ISP-07	1/02/16	3:42:25	73.6678	54.16735
Site 25	ISP-07	1/02/16	6:40:15	73.6682	54.16883
Site 25	ISP-07	1/02/16	6:43:22	73.6679	54.16885
Site 25	ISP-07	1/02/16	6:45:28	73.6677	54.16880
Site 25	ISP-07	1/02/16	6:47:30	73.6673	54.16877
Site 25	ISP-07	1/02/16	6:50:05	73.6670	54.16873
Site 25	ISP-07	1/02/16	6:54:13	73.6670	54.16887
Site 25	ISP-07	1/02/16	7:05:23	73.6682	54.16910
Site 25	ISP-07	1/02/16	7:30:47	73.6668	54.16917
Site 25	TMR-18	1/02/16	7:44:09	73.6667	54.16900
Site 25	TMR-18	1/02/16	11:18:07	73.6548	54.17250
Site 25	DR-05	1/02/16	12:14:30	73.6477	54.17617
Site 25	DR-05	1/02/16	12:14:30	73.6477	54.17617
Site 25	T-06	1/02/16	12:25:16	73.6345	54.17717
transit	T-06	1/02/16	21:34:51	73.0930	53.19728
transit	DR-06	1/02/16	21:37:50	73.0893	53.19833
transit	DR-06	1/02/16	21:38:51	73.0893	53.19843
Site 26	TC-05	2/02/16	5:26:18	73.6998	53.01283
Site 26	TC-05	2/02/16	6:25:18	73.6998	53.01283
Site 26	TC-05	2/02/16	9:46:44	73.6813	53.00833
Site 26	DN-01	2/02/16	10:53:16	73.7163	53.00717
Site 26	DN-01	2/02/16	11:07:50	73.7168	53.00717
Site 26	SMG-03	2/02/16	11:23:17	73.7165	53.00000
Site 26	SMG-03	2/02/16	11:30:43	73.7163	53.00750
Site 27	CTD-26	3/02/16	0:05:52	73.9902	53.05995

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 27	CTD-26	3/02/16	0:26:11	73.9898	53.05992
Site 27	CTD-26	3/02/16	0:28:15	73.9897	53.05992
Site 27	BP-19	3/02/16	0:41:47	73.9900	53.06015
Site 27	BP-19	3/02/16	0:51:17	73.9896	53.06013
Site 27	TMR-19	3/02/16	1:03:30	73.9891	53.05927
Site 27	TMR-19	3/02/16	1:16:53	73.9879	53.05950
Site 28	CTD-27	3/02/16	4:32:32	73.6402	53.21280
Site 28	CTD-27	3/02/16	5:01:05	73.6407	53.21293
Site 28	BP-20	3/02/16	5:07:06	73.6402	53.21240
Site 28	BP-20	3/02/16	5:18:03	73.6403	53.21217
Site 28	TMR-20	3/02/16	5:32:06	73.6403	53.21253
Site 28	TMR-20	3/02/16	5:45:24	73.6406	53.21272
transit	EIMS	3/02/16	6:34:00	0.0000	0.00000
Site 29	CTD-28	3/02/16	8:07:46	73.3163	53.28083
SIte 29	CTD-28	3/02/16	8:30:06	73.3158	53.28067
Site 29	BP-21	3/02/16	8:50:06	73.3168	53.28083
Site 29	BP-21	3/02/16	9:05:08	73.3152	53.28117
Site 29	TMR-21	3/02/16	9:10:22	73.3152	53.28117
Site 29	TMR-21	3/02/16	9:25:42	73.3152	53.28200
Site 29	HD-03	3/02/16	9:48:20	73.3226	53.28238
Site 29	HD-03	3/02/16	10:44:26	73.3098	53.28342
Site 30	HD-04	3/02/16	11:55:34	73.2296	53.25076
Site 30	HD-04	3/02/16	12:46:55	73.2135	53.24983
Site 31	CTD-29	3/02/16	15:54:59	73.2388	52.96033
Site 31	CTD-29	3/02/16	16:18:20	73.2388	52.96050
Site 31	BP-22	3/02/16	16:29:09	73.2397	52.96033
Site 31	BP-22	3/02/16	16:48:50	73.2399	52.96030
Site 31	TMR-22	3/02/16	16:50:16	73.2400	52.96023
Site 31	TMR-22	3/02/16	17:02:48	73.2391	52.96071
Site 32	CTD-30	4/02/16	1:18:42	73.7214	53.00570
Site 32	CTD-30	4/02/16	1:35:08	73.7215	53.00568
Site 32	CTD-30	4/02/16	1:37:30	73.7213	53.00582
Site 32	BP-23	4/02/16	1:49:09	73.7211	53.00555
Site 32	BP-23	4/02/16	1:57:41	73.7210	53.00598
Site 32	TMR-23	4/02/16	2:09:12	73.7215	53.00537
Site 32	TMR-23	4/02/16	2:20:15	73.7218	53.00550
Site 32	ISP-08	4/02/16	7:08:45	73.7207	53.00583
Site 32	ISP-08	4/02/16	7:12:29	73.7208	53.00550
Site 32	ISP-08	4/02/16	7:16:46	73.7208	53.00567
Site 32	ISP-08	4/02/16	7:20:33	73.7207	53.00600
Site 32	ISP-08	4/02/16	8:37:34	73.7212	53.00567
Site 32	ISP-08	4/02/16	8:40:43	73.7212	53.00567
Site 32	ISP-08	4/02/16	8:42:43	73.7210	53.00583
Site 32	ISP-08	4/02/16	8:44:50	73.7212	53.00567

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 33	CTD-31	4/02/16	10:32:52	73.6068	53.00333
Site 33	CTD-31	4/02/16	10:47:19	73.6068	53.00367
Site 33	BP-24	4/02/16	10:58:37	73.6068	53.00383
Site 33	BP-24	4/02/16	11:03:24	73.6068	53.00400
Site 33	TMR-24	4/02/16	11:26:33	73.6067	53.00283
Site 33	TMR-24	4/02/16	11:35:46	73.6067	53.00300
Site 33	ISP-09	4/02/16	11:48:21	73.6067	53.00333
Site 33	ISP-09	4/02/16	11:52:07	73.6067	53.00350
Site 33	ISP-09	4/02/16	12:43:09	73.6068	53.00350
Site 33	ISP-09	4/02/16	12:47:17	73.6068	53.00350
Site 34	HD-05	5/02/16	1:01:54	73.5504	52.96920
Site 34	HD-05	5/02/16	1:30:15	73.5347	52.96987
Site 34	HD-05	5/02/16	2:16:02	73.5341	52.96942
Site 35	SMG-04	5/02/16	11:04:08	72.6897	53.01000
Site 35	SMG-04	5/02/16	11:21:26	72.6892	53.01114
Site 19	SMG-05	5/02/16	11:56:48	72.6565	53.01800
Site 19	SMG-05	5/02/16	12:06:59	72.6562	53.01950
transit	EIMS	5/02/16	12:34:00	0.0000	0.00000
Site 23	HD-06	5/02/16	13:33:01	72.6087	53.06650
Site 23	HD-06	5/02/16	14:47:12	72.5958	53.06707
Site 36	HD-07	5/02/16	16:16:17	72.5574	53.05201
Site 36	HD-07	5/02/16	17:17:25	72.5453	53.04950
Site 20	CTD-32	6/02/16	1:41:57	72.6603	53.03343
Site 20	CTD-32	6/02/16	3:51:51	72.6606	53.03245
Site 20	CTD-32	6/02/16	3:58:12	72.6606	53.03245
Site 20	CTD-32	6/02/16	4:27:48	72.6607	53.03247
Site 20	CTD-32	6/02/16	5:53:41	72.6619	53.03332
Site 20	CTD-32	6/02/16	5:57:31	72.6620	53.03332
Site 20	CTD-33	6/02/16	7:26:51	72.6628	53.03283
Site 20	CTD-33	6/02/16	10:31:56	72.6608	53.03517
Site 20	CTD-34	6/02/16	12:02:56	72.6604	53.03278
Site 20	CTD-34	6/02/16	12:17:21	72.6622	53.03467
Site 20	TMR-25	6/02/16	12:55:42	72.6602	53.03200
Site 20	TMR-25	6/02/16	13:12:53	72.6640	53.01800
Site 37	CTD-35	6/02/16	20:21:41	72.6602	53.02879
Site 37	CTD-35	6/02/16	20:44:55	72.6607	53.02869
Site 37	TMR-26	6/02/16	20:54:38	72.6608	53.02871
Site 37	TMR-26	6/02/16	21:09:11	72.6607	53.02856
Site 38	CTD-36	6/02/16	21:47:32	72.6687	53.03340
Site 38	CTD-36	6/02/16	22:05:49	72.6690	53.03353
Site 38	CTD-36	6/02/16	22:11:45	72.6688	53.03338
Site 38	TMR-27	6/02/16	22:18:03	72.6688	53.03340
Site 38	TMR-27	6/02/16	22:33:17	72.6696	53.03375
Site 39	CTD-37	6/02/16	23:04:42	72.6626	53.03897

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 39	CTD-38	6/02/16	23:48:39	72.6609	53.03799
Site 39	CTD-38	7/02/16	0:06:36	72.6616	53.03868
Site 39	CTD-38	7/02/16	0:06:36	72.6616	53.03868
Site 39	TMR-28	7/02/16	0:17:22	72.6618	53.03884
Site 39	TMR-28	7/02/16	0:32:14	72.6626	53.03924
Site 40	CTD-39	7/02/16	1:12:04	72.6534	53.03378
Site 40	CTD-39	7/02/16	1:34:57	72.6534	53.03339
Site 40	TMR-29	7/02/16	1:38:55	72.6533	53.03321
Site 40	TMR-29	7/02/16	1:52:41	72.6534	53.03362
Site 20	BP-24	7/02/16	2:28:28	72.6613	53.03332
Site 20	BP-24	7/02/16	2:42:33	72.6610	53.03347
Site 20	ISP-10	7/02/16	2:57:51	72.6610	53.03348
Site 20	ISP-10	7/02/16	3:01:25	72.6606	53.03352
Site 20	ISP-10	7/02/16	3:04:39	72.6604	53.03347
Site 20	ISP-10	7/02/16	3:10:28	72.6604	53.03326
Site 20	ISP-10	7/02/16	3:53:30	72.6607	53.03352
Site 20	ISP-10	7/02/16	3:57:31	72.6608	53.03354
Site 20	ISP-10	7/02/16	4:00:37	72.6608	53.03357
Site 20	ISP-10	7/02/16	4:02:57	72.6608	53.03364
Site 20	CTD-40	7/02/16	4:21:29	72.6609	53.03360
Site 20	CTD-40	7/02/16	4:39:38	72.6609	53.03358
Site 20	SMG-06	7/02/16	5:14:34	53.0337	72.66062
Site 20	SMG-06	7/02/16	5:15:26	72.6606	53.03337
Site 20	SMG-07	7/02/16	5:15:26	72.6595	53.03347
Site 20	SMG-07	7/02/16	5:38:26	72.6595	53.03345
Site 34	HD-08	8/02/16	3:26:23	73.5334	52.96716
Site 34	HD-08	8/02/16	3:53:06	73.5333	52.96742
Site 34	HD-09	8/02/16	4:41:00	73.5285	52.96877
Site 34	HD-09	8/02/16	5:12:41	73.5241	52.96937
Site 41	CTD-41	8/02/16	19:33:01	74.0201	52.92228
Site 41	CTD-41	8/02/16	20:00:08	74.0215	52.92200
Site 41	CTD-41	8/02/16	20:02:40	74.0218	52.92214
Site 41	BP-25	8/02/16	20:14:52	74.0240	52.92173
Site 41	BP-25	8/02/16	20:35:16	74.0271	52.88882
Site 41	TMR-30	8/02/16	20:43:29	74.0284	52.92205
Site 41	TMR-30	8/02/16	21:05:17	74.0278	52.92386
Site 42	CTD-42	8/02/16	23:00:28	74.3206	52.83877
Site 42	CTD-42	8/02/16	23:07:49	74.3241	52.84069
Site 43	CTD-43	9/02/16	0:04:51	74.4010	52.81249
Site 43	CTD-43	9/02/16	0:20:52	74.4025	52.80933
Site 43	CTD-43	9/02/16	0:23:19	74.4018	52.80840
Site 44	CTD-44	9/02/16	7:19:44	74.7921	52.70831
Site 44	CTD-44	9/02/16	8:05:41	74.7920	52.69669
Site 44	BP-26	9/02/16	8:19:37	74.7907	52.69413

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
Site 44	BP-26	9/02/16	8:46:13	74.7895	52.68596
Site 44	TMR-31	9/02/16	9:30:13	74.7911	52.70900
Site 44	TMR-31	9/02/16	10:14:12	74.4517	52.70342
transit	DR-07	9/02/16	21:52:38	75.0004	52.68730
transit	DR-07	9/02/16	21:53:32	75.0030	52.68615
Site 45	CTD-45	10/02/16	1:07:50	75.2566	52.53867
Site 45	CTD-45	10/02/16	1:42:54	75.2618	52.54230
Site 45	CTD-45	10/02/16	1:44:59	75.2624	52.54282
Site 45	TMR-32	10/02/16	1:52:47	75.2632	52.54416
Site 45	TMR-32	10/02/16	2:20:57	75.2711	52.54929
Site 45	BP-27	10/02/16	2:29:02	75.2732	52.55108
Site 45	BP-27	10/02/16	2:53:36	75.2777	52.55427
Site 46	CTD-46	10/02/16	6:50:07	75.6030	52.41045
Site 46	CTD-46	10/02/16	7:42:44	75.6066	52.40889
Site 46	BP-28	10/02/16	7:51:56	75.6072	52.40833
Site 46	BP-28	10/02/16	8:19:32	75.6080	52.40832
Site 46	TMR-33	10/02/16	8:23:45	75.6080	52.40832
Site 46	TMR-33	10/02/16	9:13:58	75.6063	52.40717
Site 47	CTD-47	10/02/16	11:50:50	76.0037	52.29850
SIte 47	CTD-47	10/02/16	12:46:49	76.0065	52.30167
Site 47	BP-29	10/02/16	12:58:34	76.0073	52.30250
Site 47	BP-29	10/02/16	13:23:45	76.0088	52.30421
Site 47	TMR-34	10/02/16	13:32:58	76.0099	52.30530
Site 47	TMR-34	10/02/16	14:31:16	76.0153	52.31023
transit	DR-08	10/02/16	21:15:47	75.2012	52.36402
transit	DR-08	10/02/16	21:16:49	75.1999	52.36405
transit	DR-08	10/02/16	21:17:08	75.1997	52.36487
transit	DR-08	10/02/16	21:17:24	75.1993	52.36402
Site 42	CTD-48	11/02/16	6:17:45	74.3206	52.83800
Site 42	CTD-48	11/02/16	6:38:33	74.3228	52.83787
Site 42	BP-30	11/02/16	7:41:42	74.3207	52.83677
Site 42	BP-30	11/02/16	7:57:38	74.3206	52.83605
Site 42	TMR-35	11/02/16	8:08:17	74.3206	52.83561
Site 42	TMR-35	11/02/16	8:26:41	74.3205	52.84317
Site 48	CTD-49	11/02/16	13:38:12	73.7090	53.00756
Site 48	CTD-49	11/02/16	13:51:10	73.7085	53.00742
Site 48	BP-31	11/02/16	14:01:07	73.7084	53.00740
Site 48	BP-31	11/02/16	14:10:08	73.7087	53.00753
Site 48	TMR-36	11/02/16	14:16:11	73.7088	53.00748
Site 48	TMR-36	11/02/16	14:29:32	73.7085	53.00761
transit	CTD-50	11/02/16	14:50:00	73.7165	53.01167
Site 49	CTD-51	11/02/16	14:56:48	73.7165	53.01174
Site 49	CTD-51	11/02/16	15:08:32	73.7165	53.01175
Site 49	BP-32	11/02/16	15:19:34	73.7165	53.01178

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
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Site 49	TMR 37	11/02/16	15:34:38	73.7164	53.01190
Site 49	TMR-37	11/02/16	15:43:52	73.7165	53.01183
Site 50	CTD-52	11/02/16	16:20:38	73.7245	53.00724
Site 50	CTD-52	11/02/16	16:32:28	73.7244	53.00741
Site 50	BP-33	11/02/16	16:48:56	73.7246	53.00715
Site 50	BP-33	11/02/16	16:55:00	73.7246	53.00715
Site 50	TMR-38	11/02/16	17:03:18	73.7246	53.00727
Site 50	TMR-38	11/02/16	17:13:47	73.7246	53.00720
Site 51	CTD-53	11/02/16	17:45:04	73.7167	53.00272
Site 51	CTD-53	11/02/16	18:02:05	73.7167	53.00267
Site 51	BP-34	11/02/16	18:12:44	73.7168	53.00267
Site 51	BP-34	11/02/16	18:20:38	73.7167	53.00267
Site 51	TMR-39	11/02/16	18:27:41	73.7165	53.00300
Site 51	TMR-39	11/02/16	18:39:10	73.7167	53.00283
Site 26	CTD-54	12/02/16	1:37:04	73.7164	53.00747
Site 26	CTD-54	12/02/16	5:46:53	73.7162	53.00755
Site 26	CTD-54	12/02/16	5:48:21	73.7162	53.00759
Site 26	BP-35	12/02/16	6:00:15	73.7160	53.00750
Site 26	BP-35	12/02/16	6:09:31	73.7162	53.00756
Site 26	CTD-55	12/02/16	6:33:21	73.7160	53.00773
Site 26	CTD-55	12/02/16	6:44:50	73.7161	53.00773
Site 26	CTD-55	12/02/16	6:47:22	73.7161	53.00770
Site 26	TMR-40	12/02/16	6:55:51	73.7160	53.00769
Site 26	TMR-40	12/02/16	7:07:58	73.7160	53.00767
Site 26	ISP-11	12/02/16	7:22:42	73.7162	53.00767
Site 26	ISP-11	12/02/16	7:26:56	73.7162	53.00767
Site 26	ISP-11	12/02/16	7:29:29	73.7162	53.00767
Site 26	ISP-11	12/02/16	8:58:57	73.7162	53.00750
Site 26	ISP-11	12/02/16	9:01:00	73.7162	53.00750
Site 26	ISP-11	12/02/16	9:04:18	73.7163	53.00750
Site 26	SMG-08	12/02/16	9:19:27	73.7162	53.00750
Site 26	SMG-08	12/02/16	9:40:31	73.7158	53.00817
Site 26	TC-06	12/02/16	13:09:04	73.7307	53.00833
Site 26	TC-06	12/02/16	15:49:11	73.7110	53.00633
transit	T-07	13/02/16	1:25:19	73.4449	52.74783
transit	T-07	13/02/16	2:34:48	73.5089	52.64500
transit	DR-09	13/02/16	14:15:41	77.1767	51.72900
transit	A-07	13/02/16	14:18:45	77.1930	51.72850
transit	EIMS	13/02/16	15:32:00	0.0000	0.00000
transit	A-08	13/02/16	15:56:09	77.7143	51.58917
transit	XBT-05	16/02/16	10:50:17	95.6919	47.25320
transit	XBT-06	16/02/16	10:50:18	95.7458	47.24992
transit	XBT-07	17/02/16	7:52:00	101.9318	46.82600

Station Number	Op Number	UTC date	UTC time	Lon_DD	Lat_DD
transit	XBT-08	18/02/16	2:27:22	107.2675	46.46450
transit	EIMS	18/02/16	6:51:00	0.0000	0.00000

Appendix 2 Ship's Complement Photograph

The 40 scientists, students, support staff, and artists of RV *Investigator* voyage IN2016_V01, Heard Earth-Ocean-Biosphere Interactions (HEOBI).

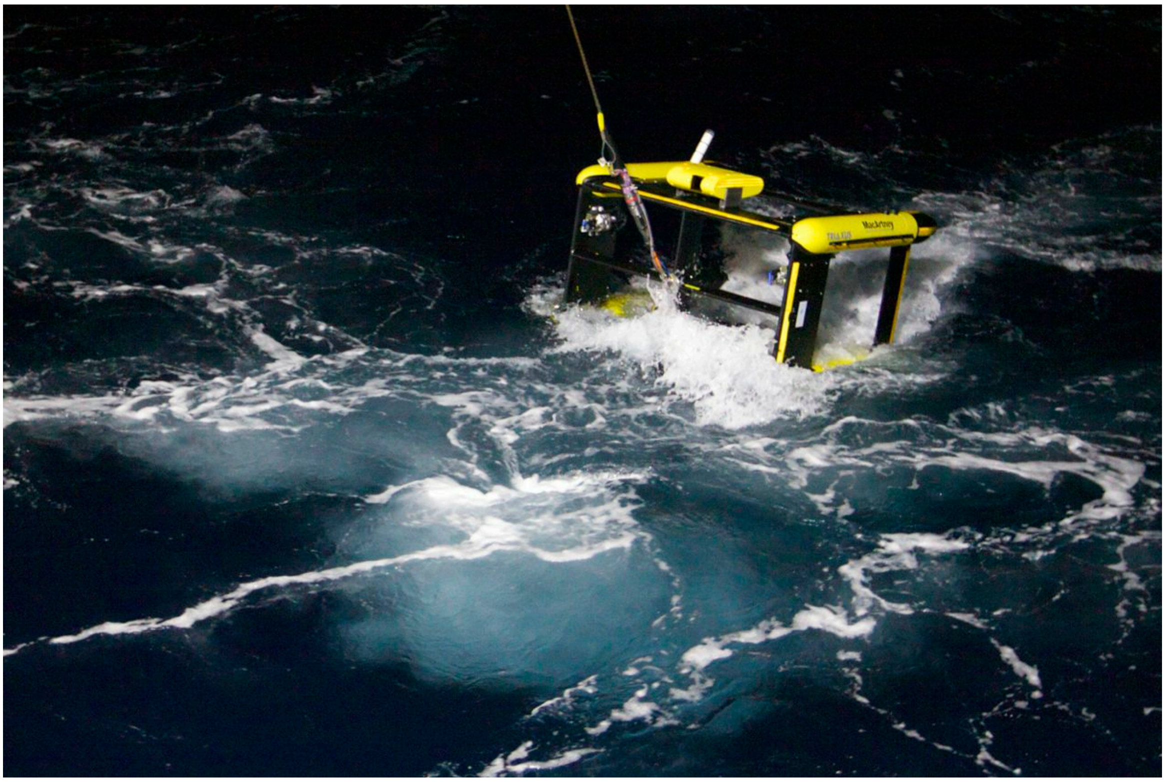
Appendix 3 Voyage Photographs

RV *Investigator* at Victoria Quay in Fremantle prior to departure. Credit: Peter Harmsen.

Chief Scientist Prof Mike Coffin (right), Co-Chief Scientist A/Prof Andrew Bowie (center), and Co-Chief Scientist Prof Richard Arculus (left) at Victoria Quay, Fremantle, Western Australia. Credit: Peter Harmsen.

CTD deployment. Credit: Peter Harmsen.

Bio-optical package (BO-Pak) deployment, with Dr Bozena Wojtasiewicz in the foreground. Credit: Peter Harmsen.



Triaxus remotely operated towed vehicle (ROTV) deployment. Credit: Peter Harmsen.

McDonald Island (right) and Meyer Rock (left), with Prof Richard Arculus in the foreground.
Credit: Peter Harmsen.

Pumice recovered by dredging a sea knoll near the McDonald Islands, with PhD candidate Jodi Fox in the foreground. Credit: Peter Harmsen.

Fumaroles on McDonald Island. Credit: Peter Harmsen.

Smith McIntyre grab recovery near the McDonald Islands: left – Meyer Rock, center – Flat Island, right – McDonald Island. Credit: Peter Harmsen.

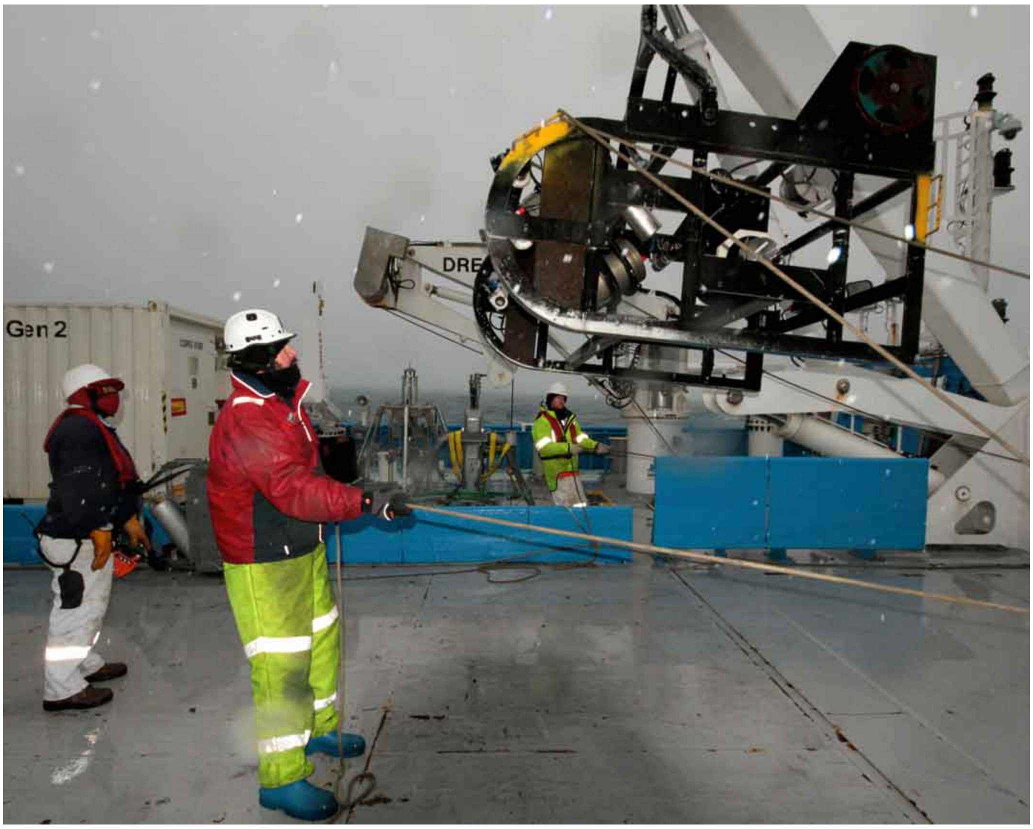
Trace metal rosette (TMR) deployment. Credit: Peter Harmsen.

Heard Island. Credit: Peter Harmsen.

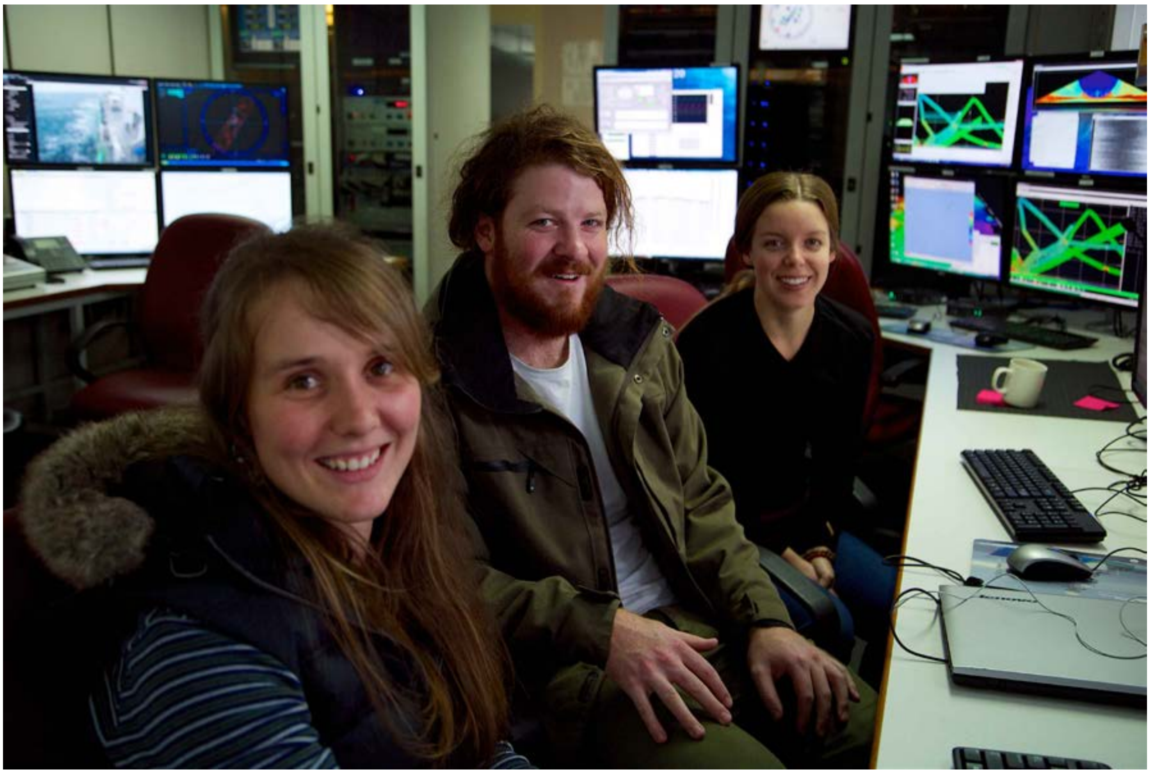
Big Ben volcanic massif, Heard Island. Credit: Peter Harmsen.

Mawson Peak on Big Ben, Heard Island. The summit of Mawson Peak is emitting vapour, and lava is flowing down the left side of the mountain over a glacier, producing steam. Credit: Peter Harmsen.

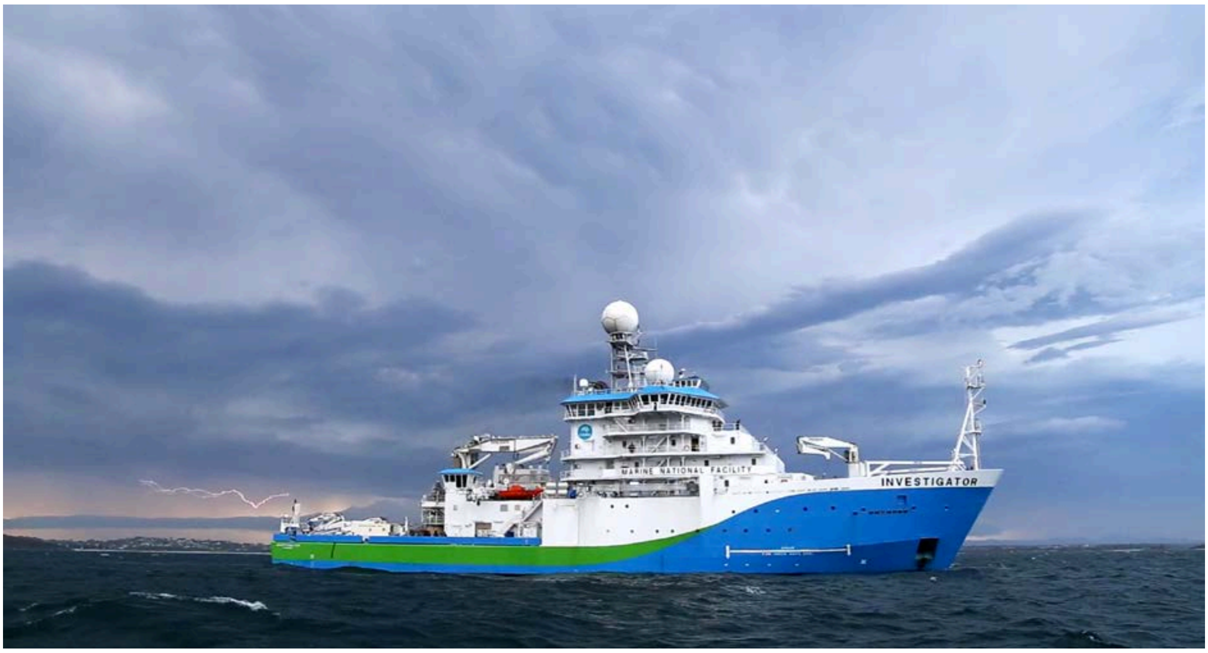
In situ pump, handled by Mark Lewis. Credit: Peter Harmsen.



Deep-tow camera, handled by Mark Lewis. Credit: Peter Harmsen.



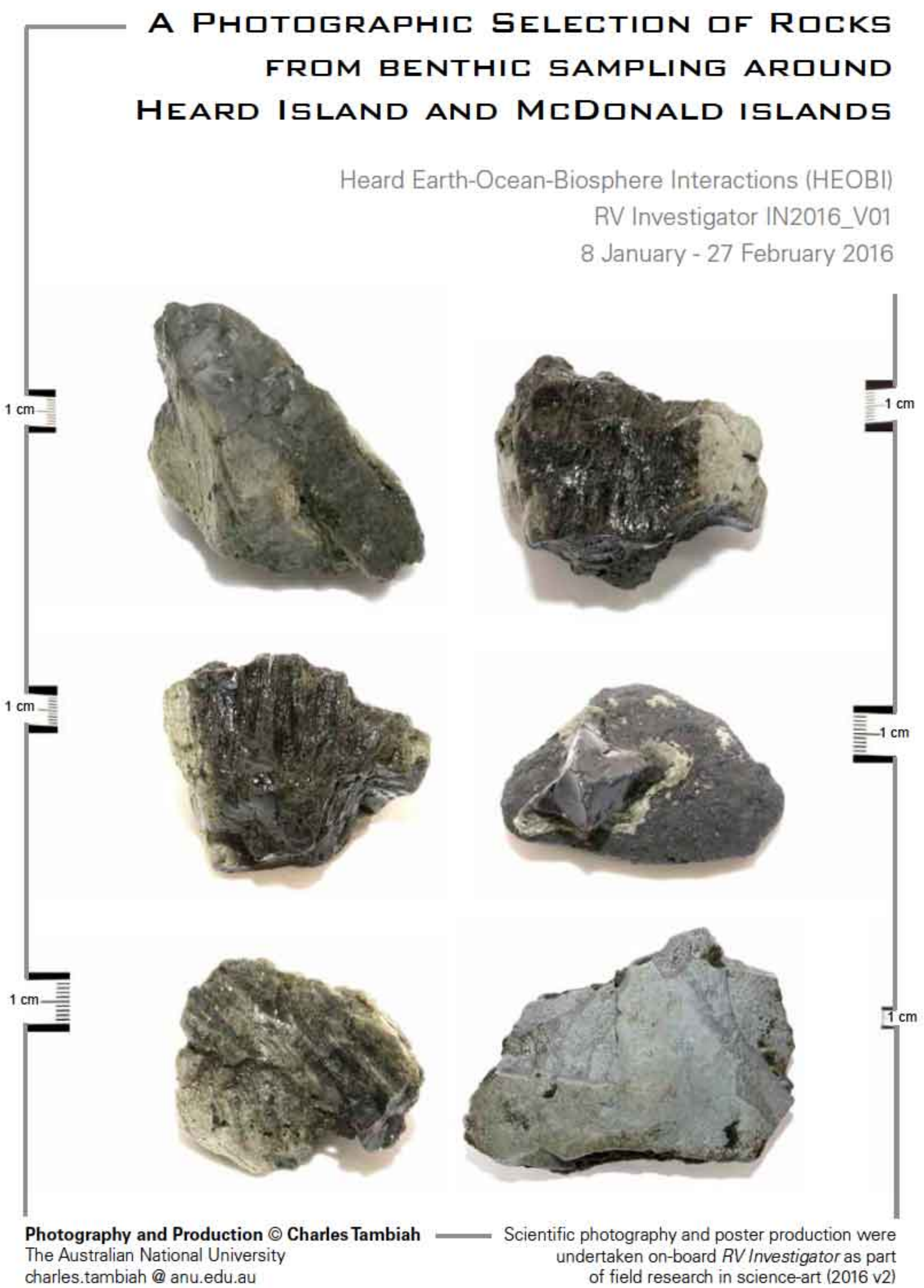
Operations room. Left – PhD candidate Sally Watson, center – Nic Polmear, right – Anna Bradney. Credit: Peter Harmsen.



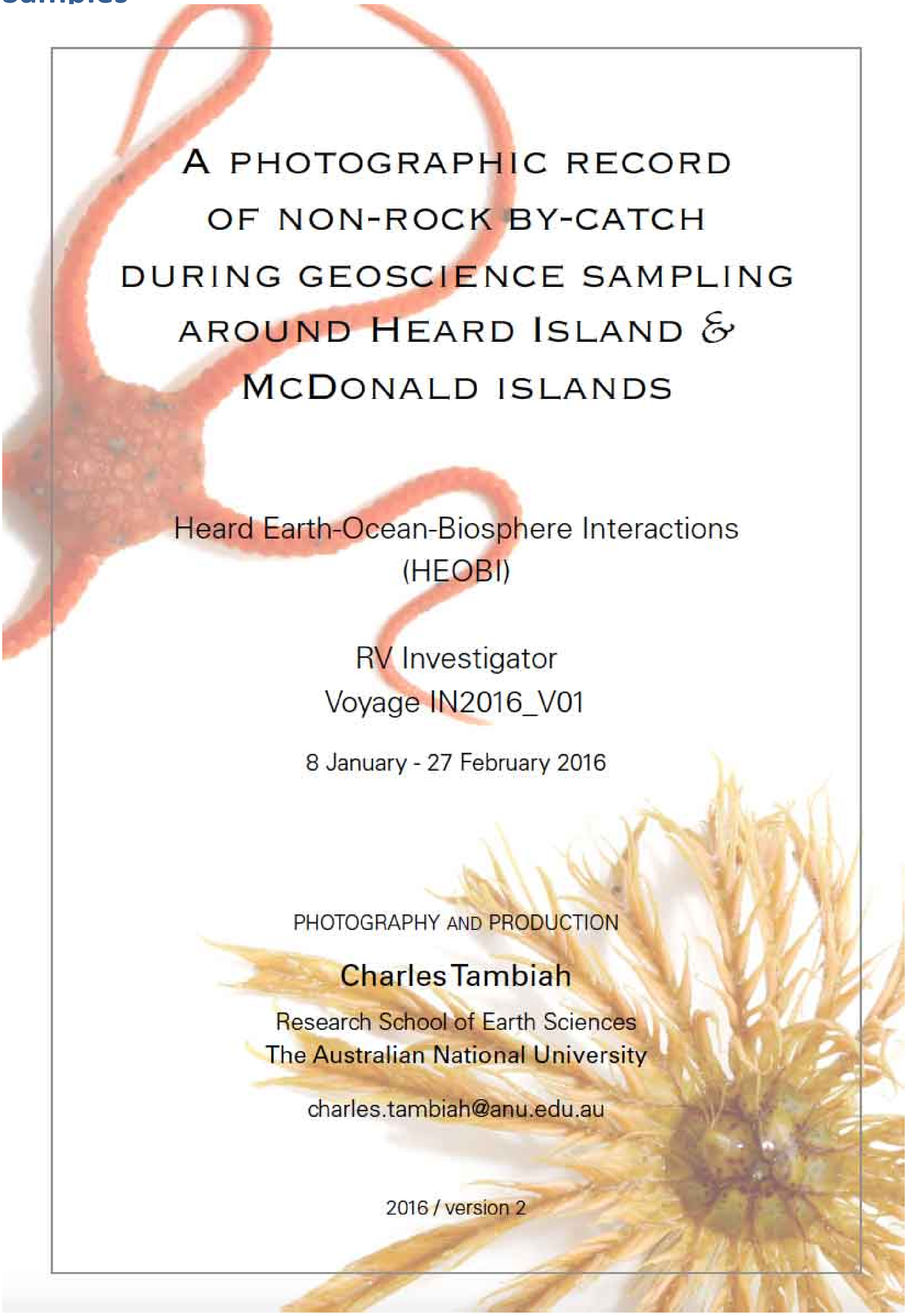
Lightning offshore Albany, Western Australia, near the conclusion of the medical evacuation. Credit: Peter Harmsen.

Steaming up the Derwent to Hobart at the conclusion of the voyage. Credit: Peter Harmsen.

Appendix 4 Rocks Recoverd from Dredges



Appendix 5 Biota Recovered from Dredges and Grab Samples



A PHOTOGRAPHIC RECORD
OF NON-ROCK BY-CATCH
DURING GEOSCIENCE SAMPLING
AROUND HEARD ISLAND &
MCDONALD ISLANDS

Heard Earth-Ocean-Biosphere Interactions
(HEOBI)

RV Investigator
Voyage IN2016_V01

8 January - 27 February 2016

PHOTOGRAPHY AND PRODUCTION
Charles Tambiah
Research School of Earth Sciences
The Australian National University
charles.tambiah@anu.edu.au

2016 / version 2

A PHOTOGRAPHIC RECORD OF NON-ROCK BY-CATCH DURING GEOSCIENCE SAMPLING AROUND HEARD ISLAND AND MCDONALD ISLANDS

Heard Earth-Ocean-Biosphere Interactions (HEOBI)
RV Investigator IN2016_V01
8 January - 27 February 2016

Field Notes

- All biota I photographed for this compilation were by-catch brought on deck during geoscience ocean floor sampling on the research voyage RV Investigator IN2016_V01.
- The two rock/sediment sampling techniques used during the voyage were the 'Smith-McIntyre Grab' and the 'Rock Dredge'.
- I photographed the specimens on-board the RV Investigator and returned them to the ocean – no specimens were collected/preserved due to research requirements.
- I only photographed fully intact specimens and largely undamaged sections if relevant;
- The scale I used with each photograph was in centimetres.
- While no species-level identification was undertaken on-board, a few common groups are listed [derived from Hibberd and Moore 2009[1] – thanks to Erica Spain (UTAS) for locating this guide – and thanks to Mark Lewis (CSIRO) for insights from his fish sampling work]. Further identification, labelling and revisions will be undertaken after the voyage.

- I wish to thank the crew of the RV Investigator and the CSIRO/MNF technical staff for deploying the rock/sediment sampling devices;
- Thanks to Jodi Fox (UTAS) and Evan Draayers (UTAS) for their patience with separating biota from rock and sediment samples (despite their initial "sentiments" with handling "bugs" which came with rocks/sediments);
- I appreciate the patience extended to me with my fascination with biota and my enthusiasm to photograph what came on-deck during benthic sampling – it seems that invertebrate biota are especially challenging for most geoscientists to "relate to". To me, they were a trove of science-art inspiration and a testing ground for research processes central to science photography during expeditions.

For more information please contact:

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The Australian National University
Canberra ACT 2601
charles.tambiah@anu.edu.au

[1]Hibberd T. and Kirrily Moore. 2009. Field identification guide to Heard Island and McDonald Islands benthic invertebrates: a guide for scientific observers aboard fishing vessels. Australian Antarctic Division, Kingston, TAS. 159pp.

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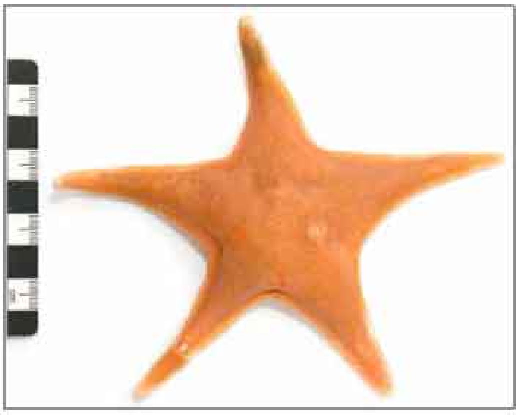

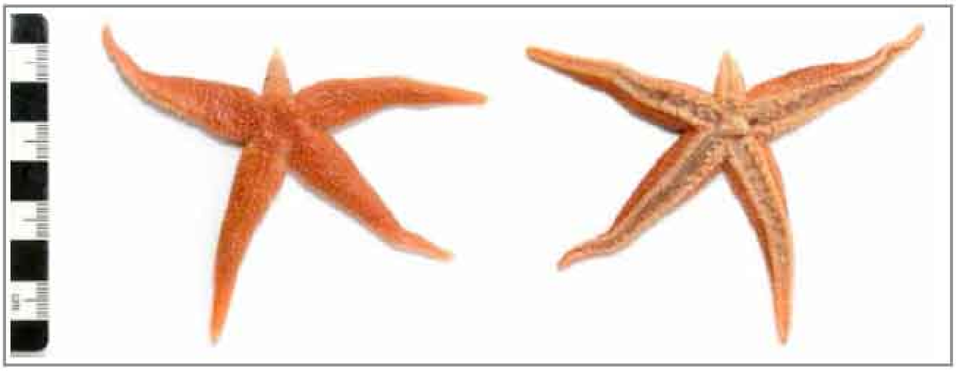

sea stars / star fish

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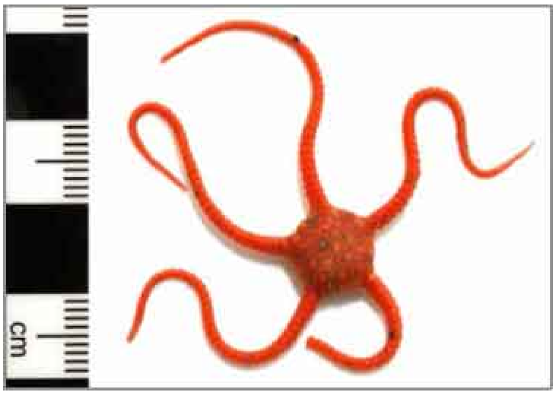

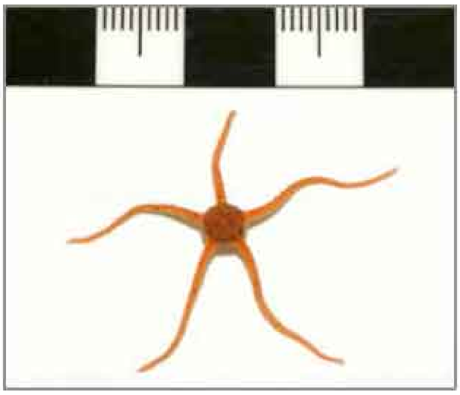

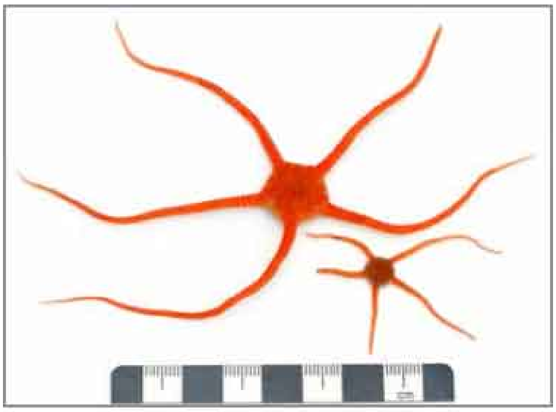

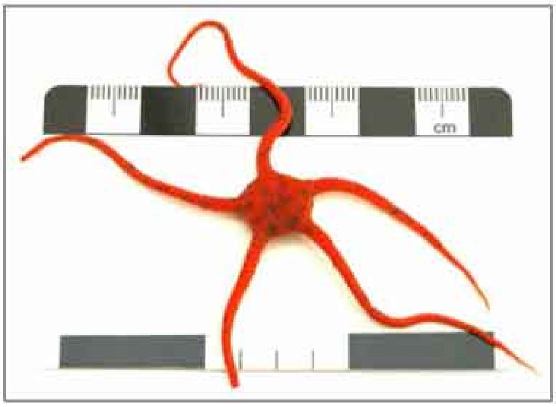

brittle stars

basket stars

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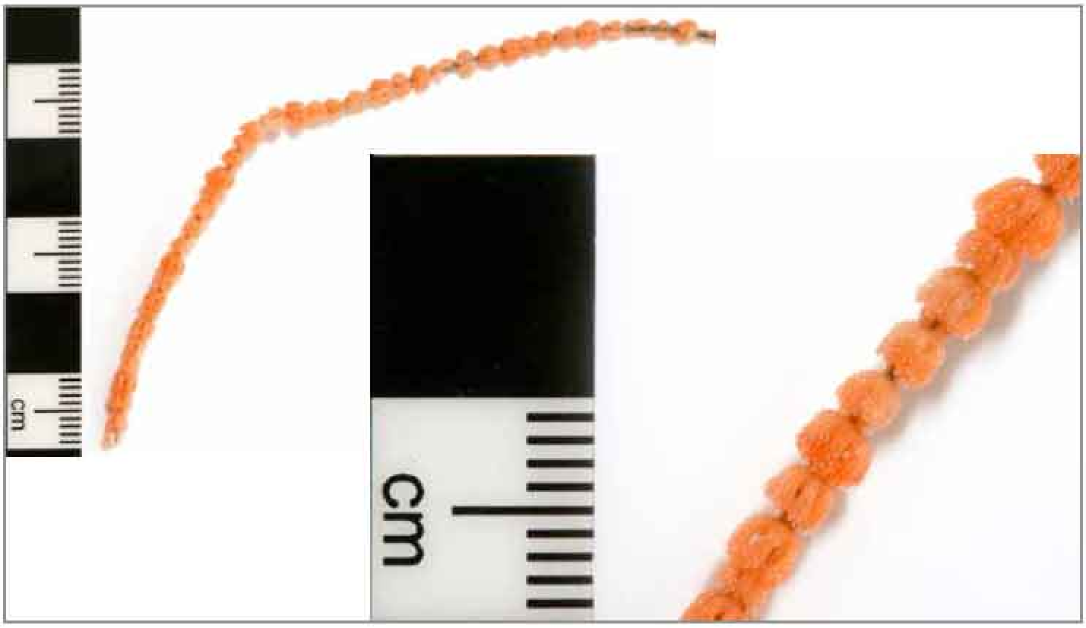
feather star



Cnidaria sp (?)

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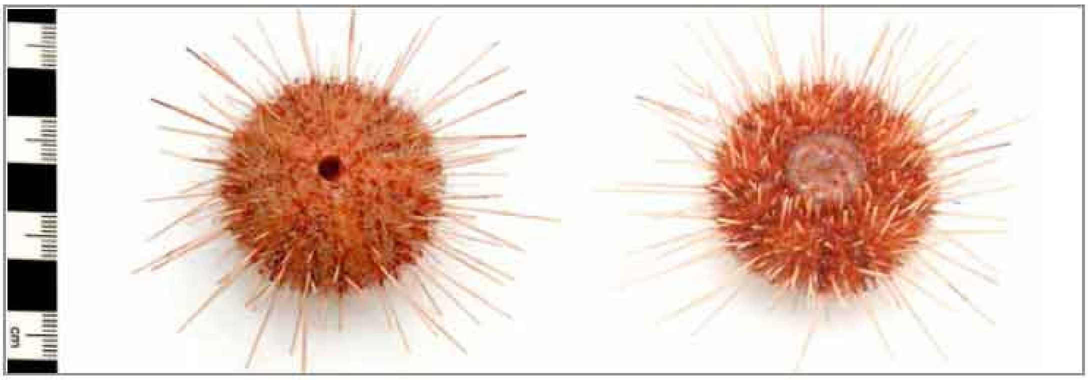

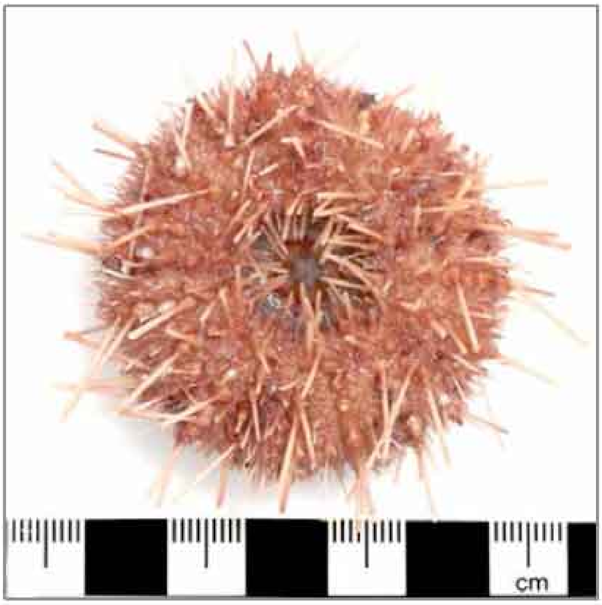

sea urchins

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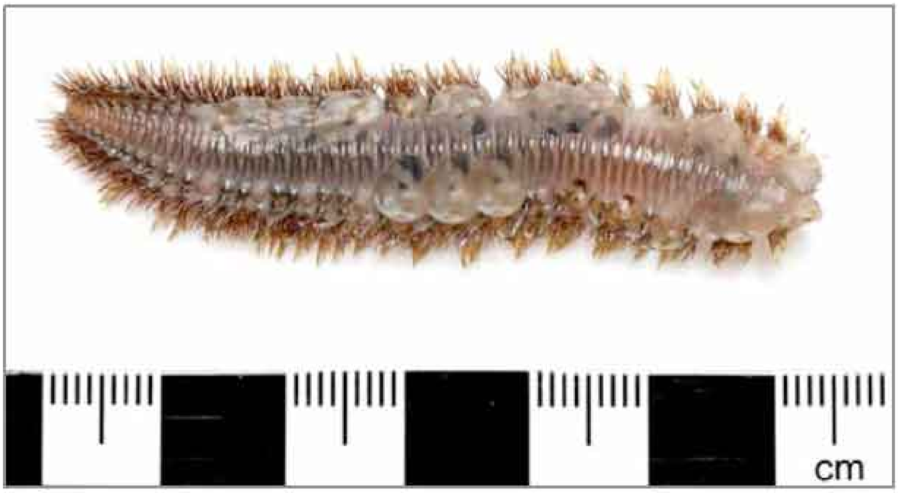
sea slater



sea mouse (?)

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tube worms

sea cucumber

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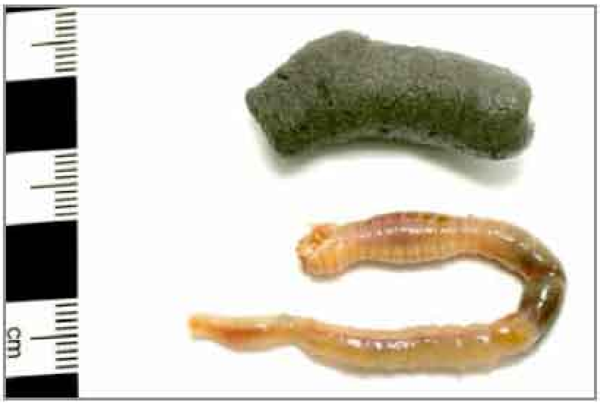

tube worms / tube anemones (?)

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tube worms

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sponges

soft coral (?)

sea squirt

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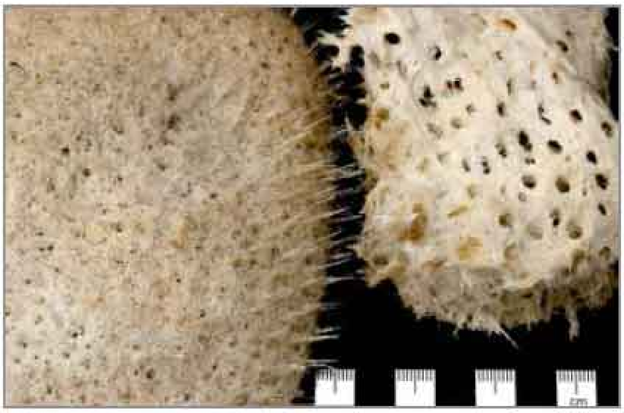

sponges

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sea snails

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bivalves

hydrocoral (?)

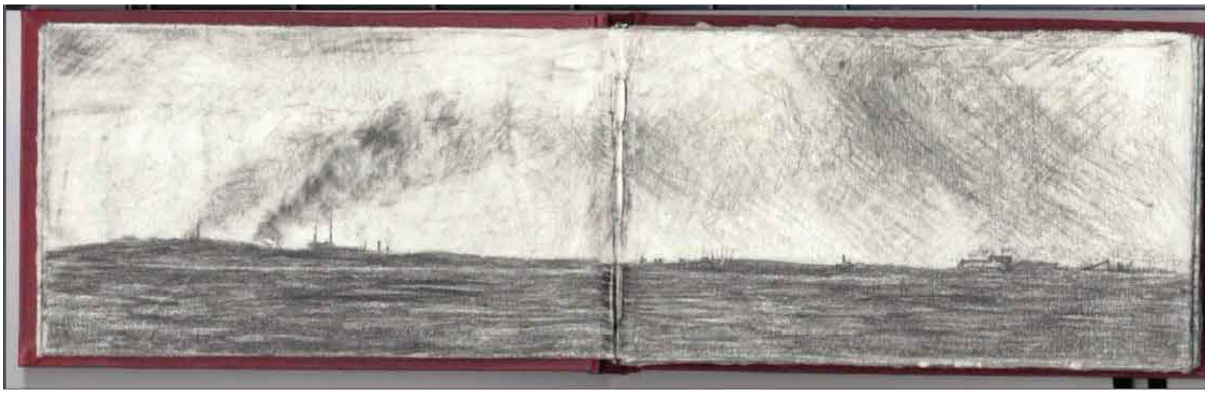
Appendix 6 Drawing

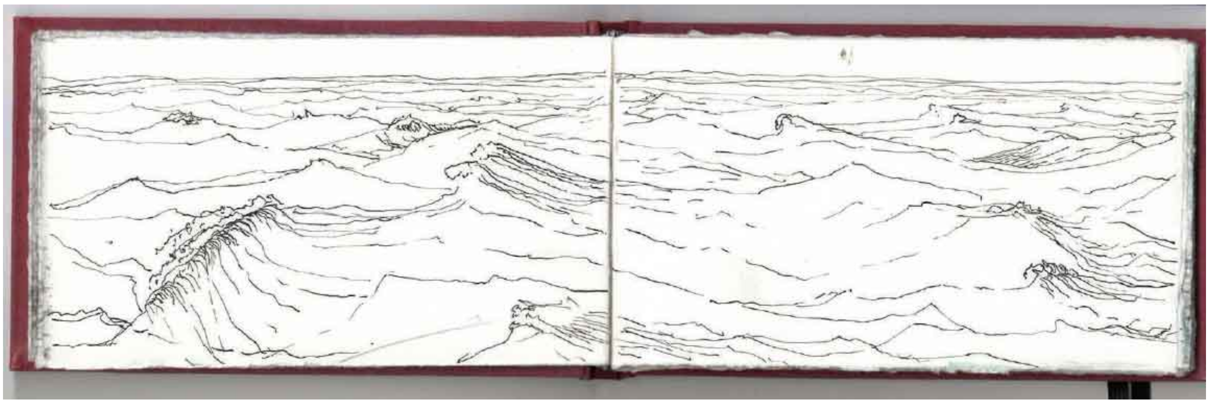
Annalise Rees

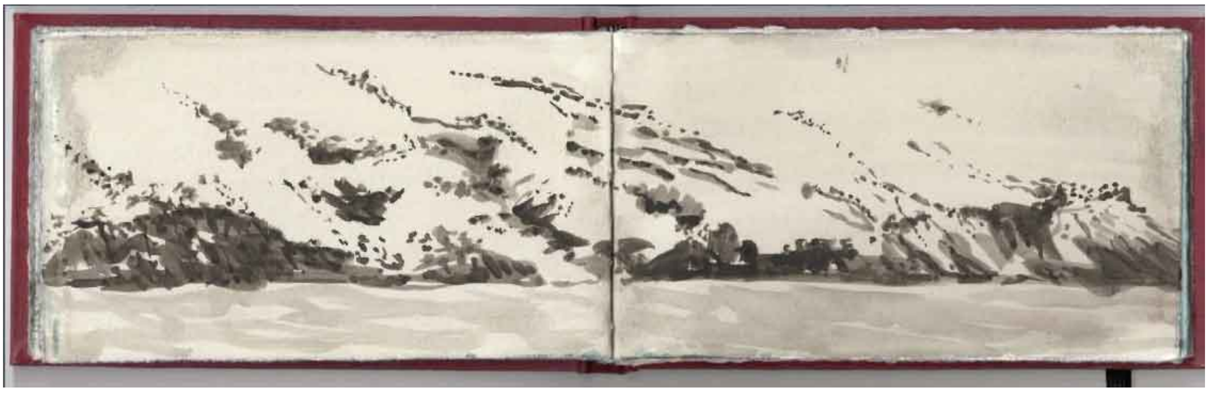
My days were spent both observing and participating in the day-to-day life of the ship. This was as much a part of the experience of being at sea as was learning about the scientific research that was being carried out by the international team of marine scientists. I have also had opportunity to collaborate with one of my fellow artistic voyagers, dancer/choreographer James Batchelor. All of these aspects of my experience on board have been part of my drawing research, one of collecting information – a drawing out from the world, a gathering process. This, combined with observational drawing, has helped me make sense of something which was previously unknown and unfamiliar. An interesting opportunity to expand my practice and thinking has been provided by this journey. The complex instrumentation and equipment on board the Investigator also uses drawing processes to collect and translate data, contributing to knowledge about the effects of iron in the world's oceans. It is a contrasting and yet similar way of making sense of the world via a drawn understanding. The opportunity to stand alongside scientists and crew and share such a unique experience, opens up a collective understanding and appreciation of something that words often fail to describe. The drawn and the visual provide an alternative means of translating and communicating human experience and phenomena. This has the potential to speak across disciplinary boundaries, backgrounds and conventions to a broad audience. My presence on the voyage has not only continued a historical tradition of artists being involved with scientific voyages of discovery. It has potentially extended and expanded perceptions of knowledge and information gathering. It raises important questions about the nature of research and how the human is inextricably entangled in the research process, whether that be scientific or artistic.

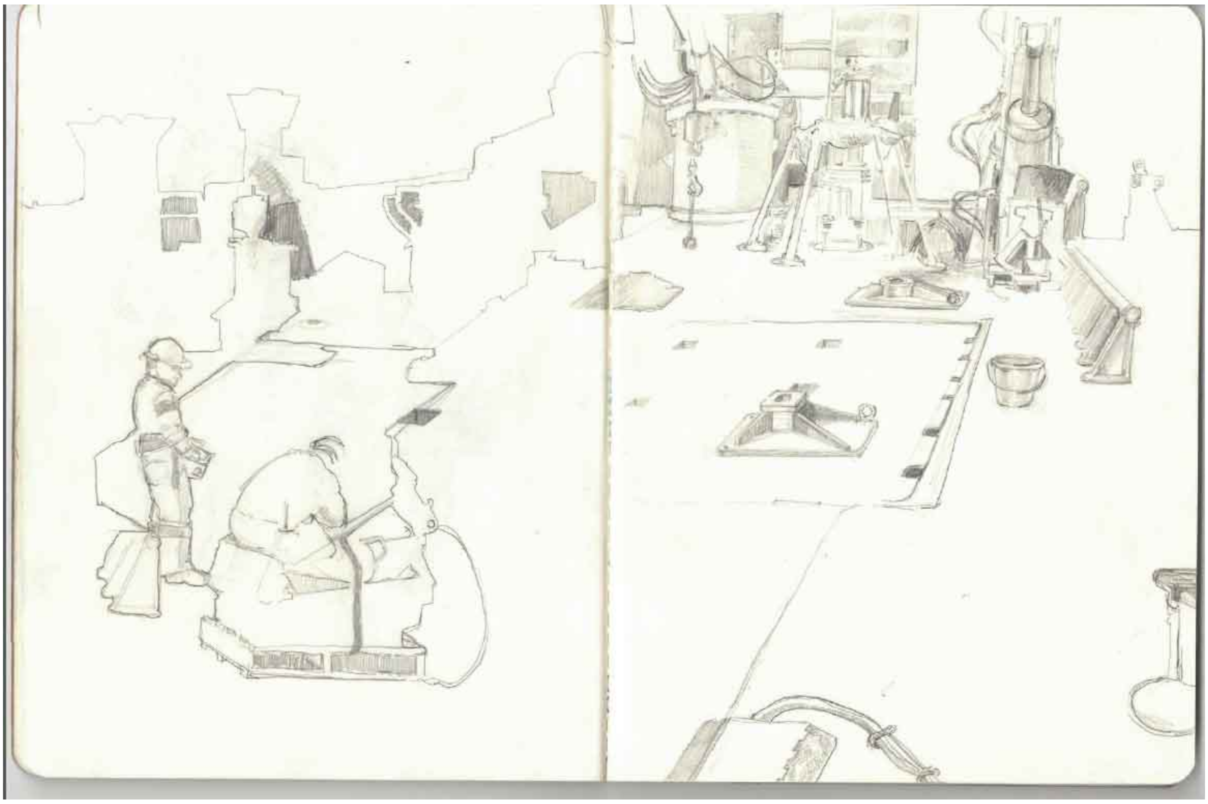
Outputs and data include:

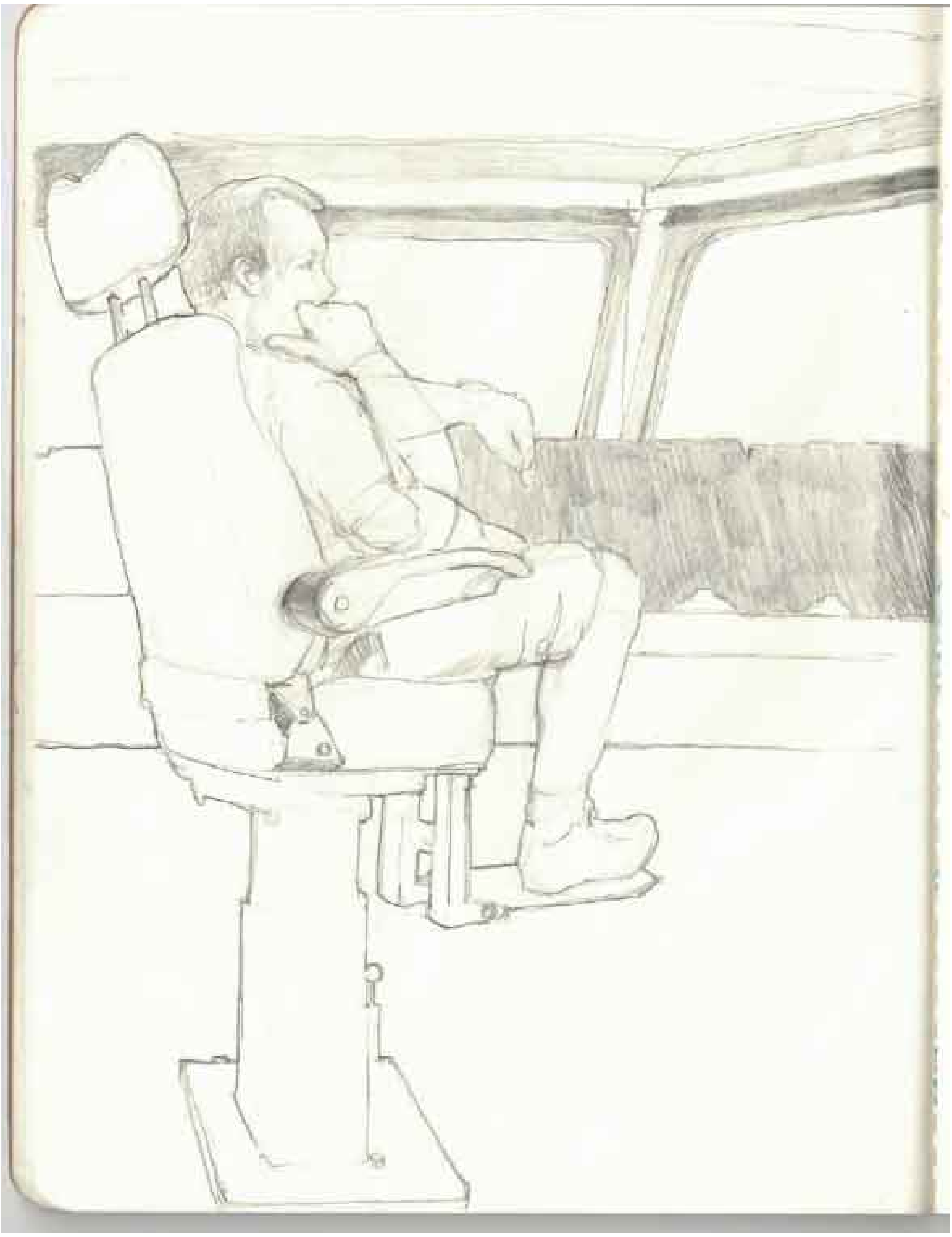
- 156 sketches completed during the voyage.
- 2300 still images.
- 6.5 hours of moving image.
- 3.5 hours of sound.

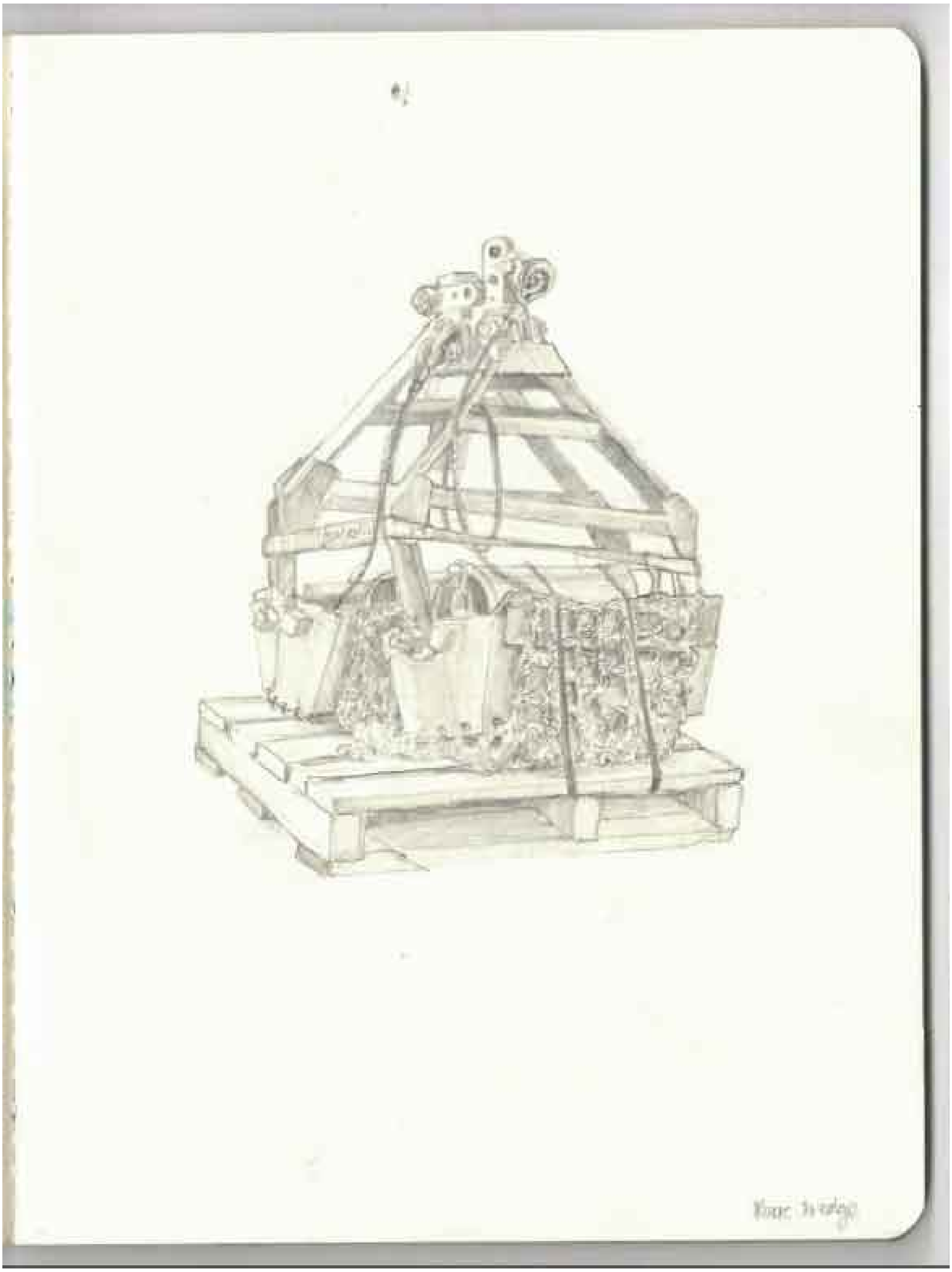


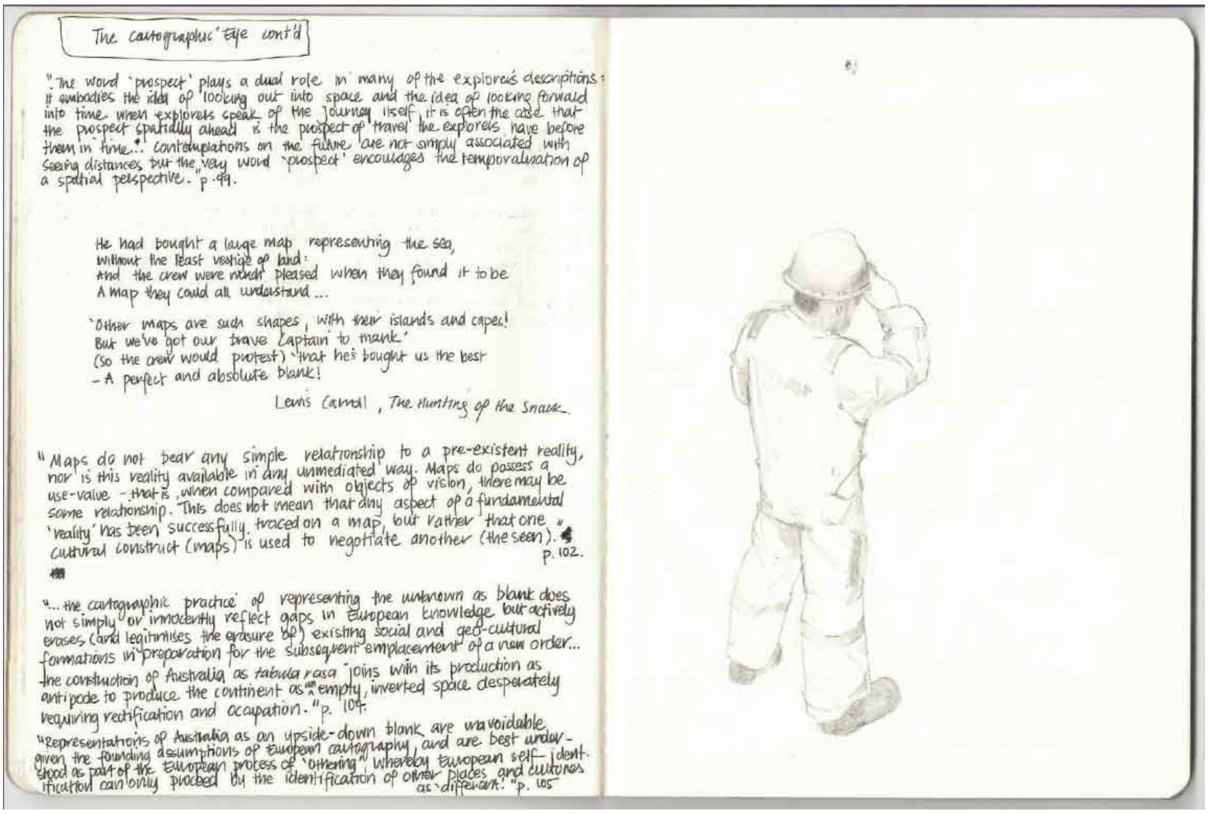


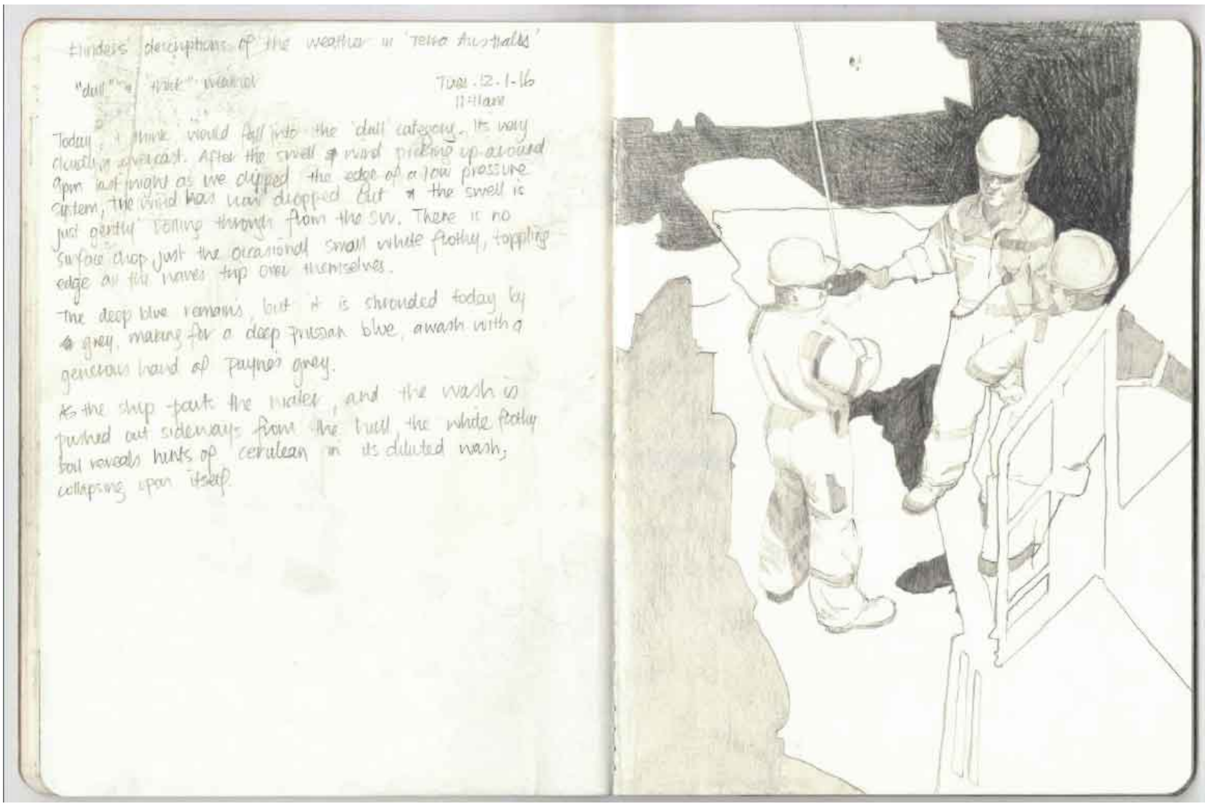


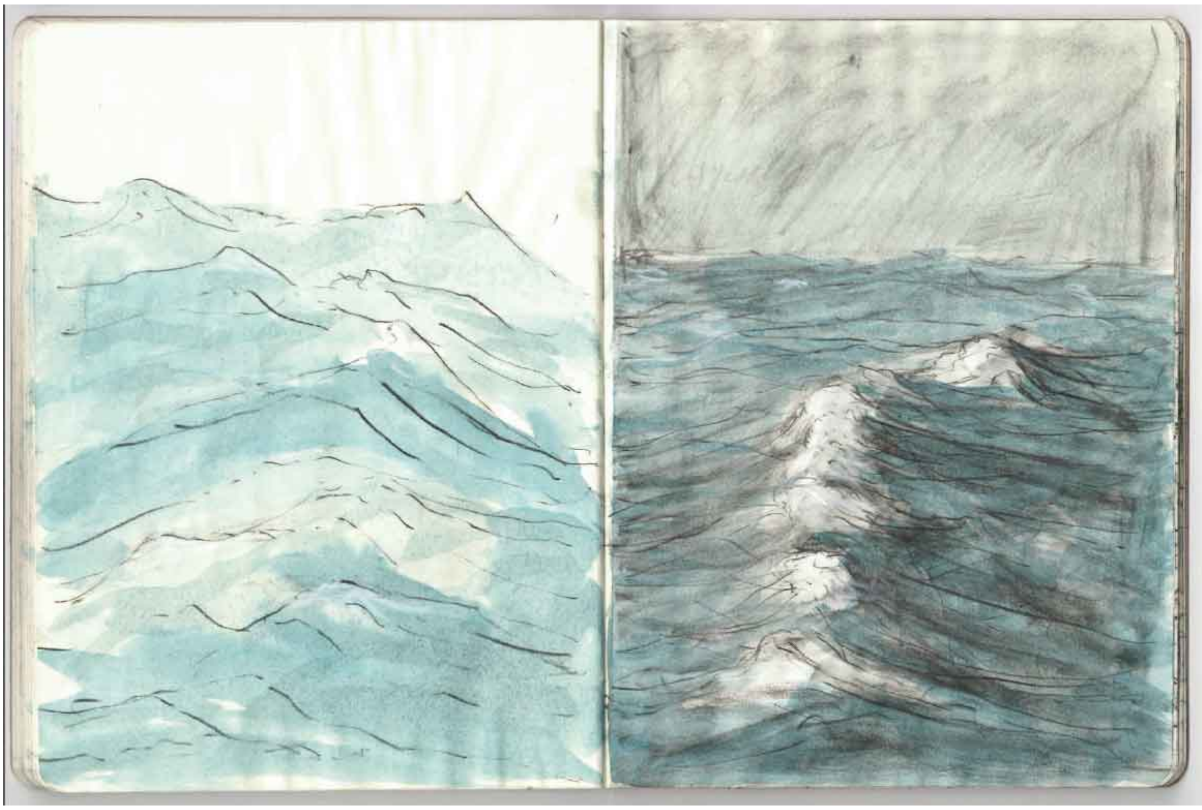


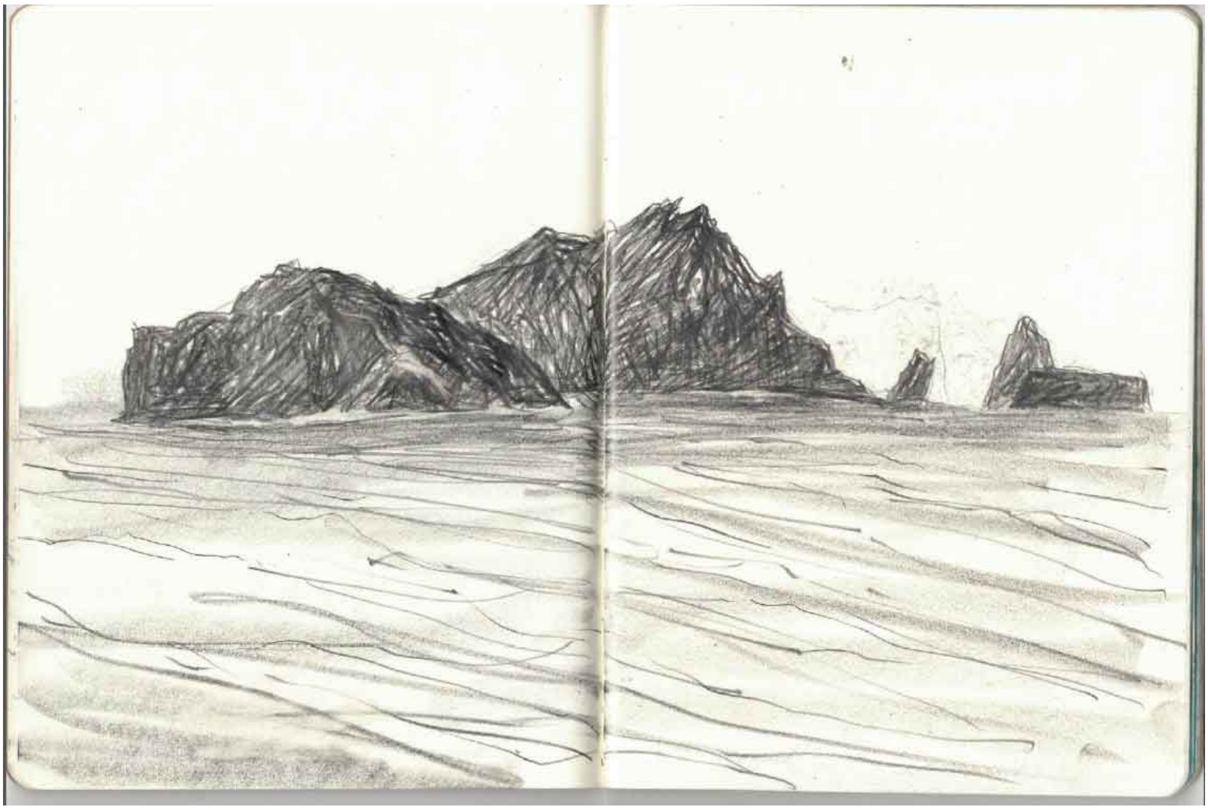


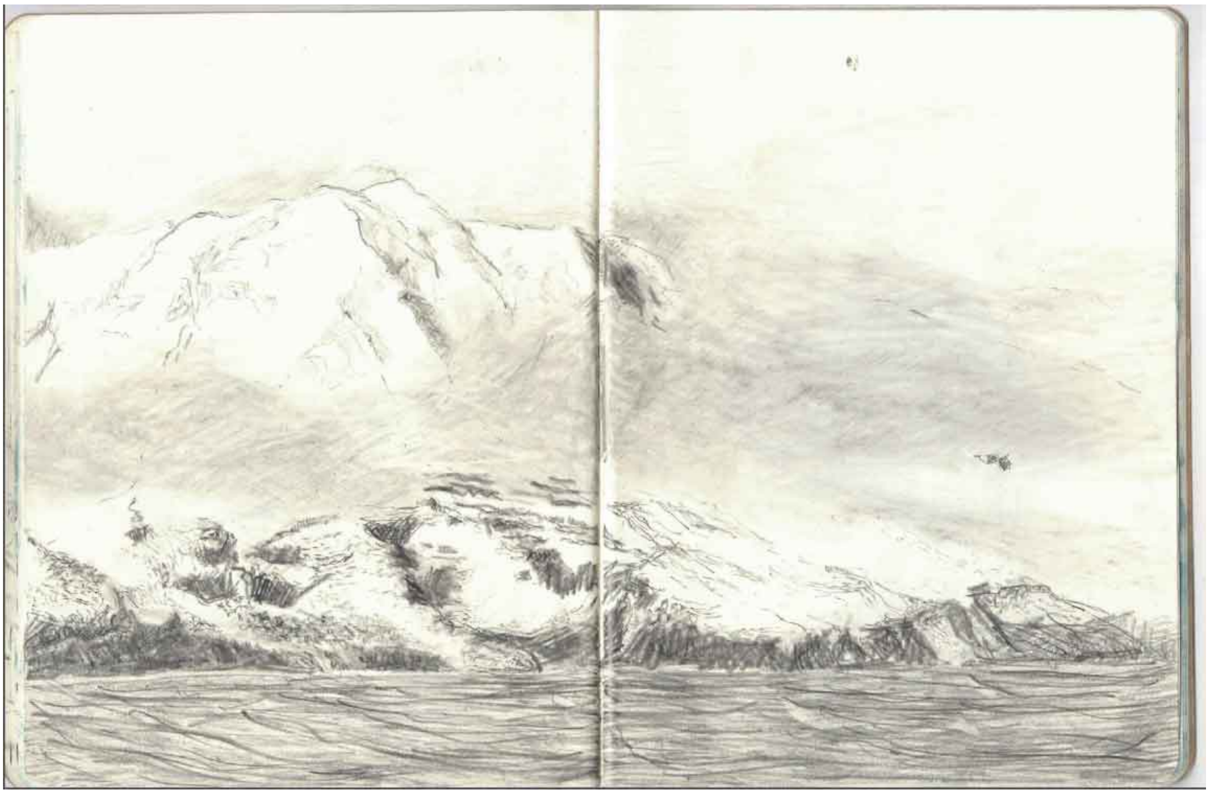


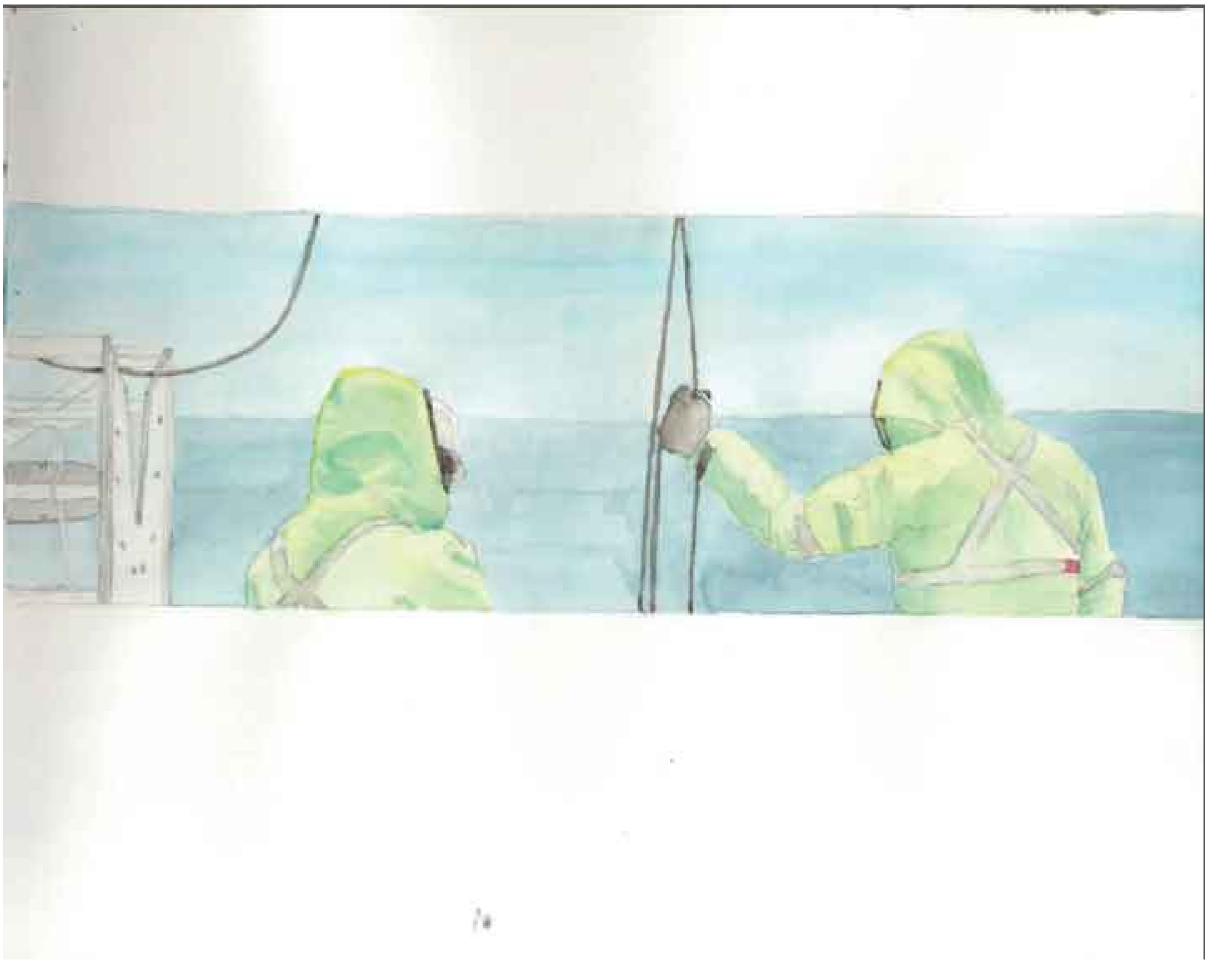

The cartographic Eye cont'd
"The word 'prospect' plays a dual role in many of the explorers descriptions: it embodies the idea of looking out into space and the idea of looking forward into time. When explorers speak of the journey itself, it is often the case that the prospect spatially ahead is the prospect of travel the explorers have before them in time... contemplations on the future are not simply associated with seeing distances but the very word 'prospect' encourages the temporalisation of a spatial perspective." p. 99.
He had bought a large map representing the sea,
without the least vestige of land:
And the crew were much pleased when they found it to be
A map they could all understand...
'Other maps are such shapes, with their islands and capes!
But we've got our brave Captain to thank'
(So the crew would protest) 'that he's bought us the best
- A perfect and absolute blank!
Lewis Carroll, The Hunting of the Snark
"Maps do not bear any simple relationship to a pre-existent reality, nor is this reality available in any unmediated way. Maps do possess a use-value - that is, when compared with objects of vision, there may be some relationship. This does not mean that any aspect of a fundamental 'reality' has been successfully traced on a map, but rather that one cultural construct (maps) is used to negotiate another (the seen)." p. 102.
"... the cartographic practice of representing the unknown as blank does not simply or innocently reflect gaps in European knowledge but actively erases (and legitimises the erasure of) existing social and geo-cultural formations in preparation for the subsequent emplacement of a new order... the construction of Australia as tabula rasa joins with its production as antipode to produce the continent as an empty, inverted space desperately requiring rectification and occupation." p. 104.
"Representations of Australia as an upside-down blank are unavoidable given the founding assumptions of European cartography, and are best understood as part of the European process of 'othering' whereby European self-identification can only proceed by the identification of other places and cultures as 'different'." p. 105

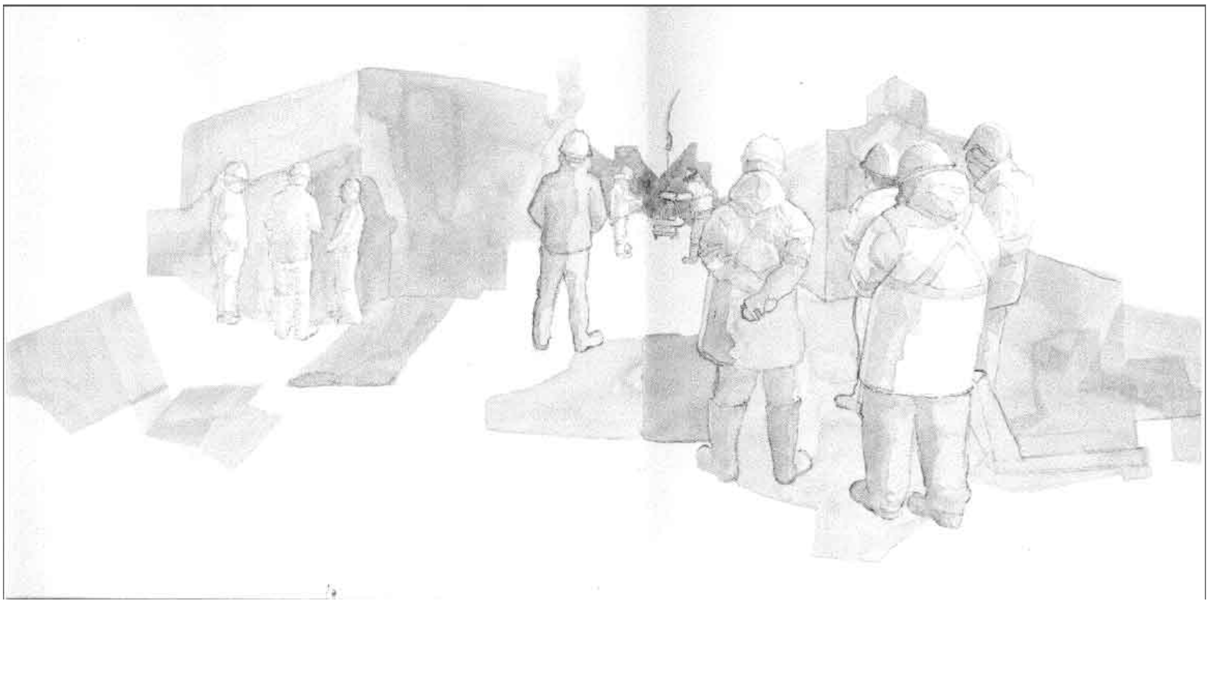

Flinders' descriptions of the weather in 'Terra Australis'
Tues. 12-1-16
The deep blue remains, but it is shrouded today by grey, making for a deep Prussian blue, awash with a generous hand of Payne's grey.
As the ship parts the water, and the wash is pushed out sideways from the hull, the white frothy boil reveals hints of cerulean in its diluted wash, collapsing upon itself.







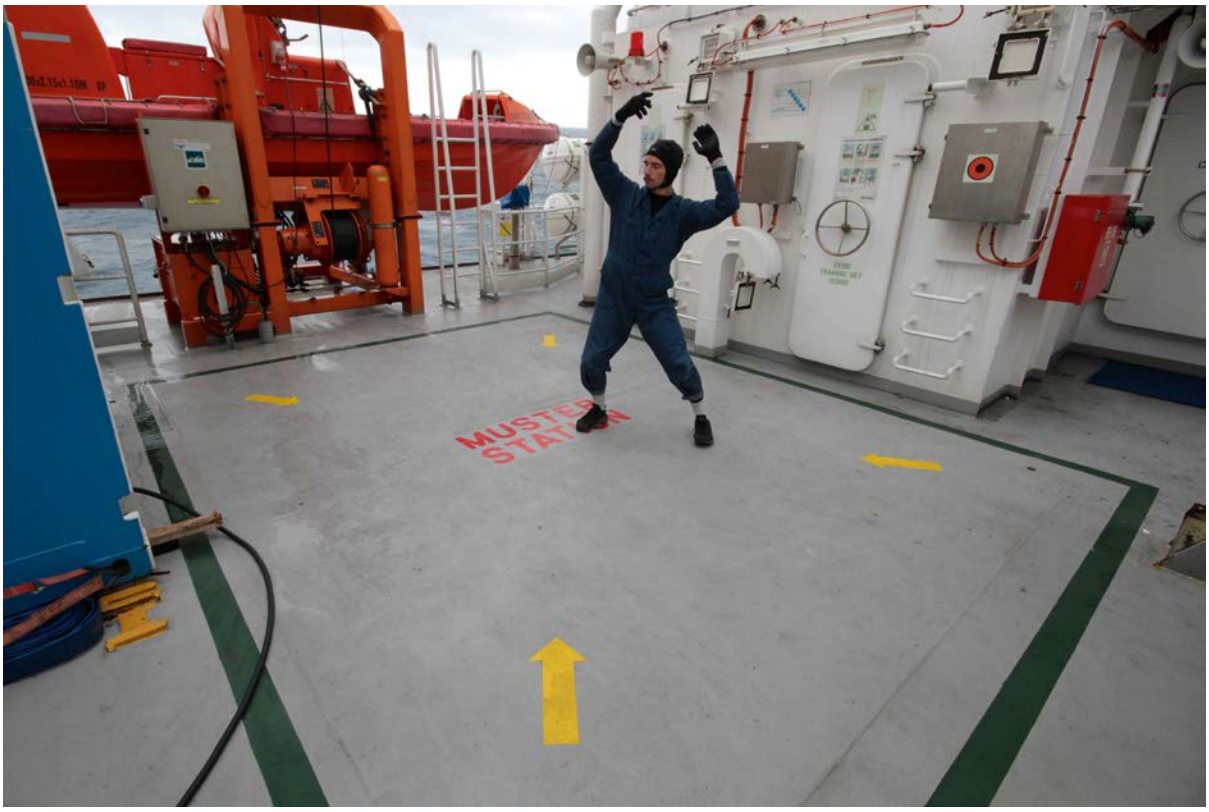




Appendix 7 Choreography

James Batchelor

As a choreographer in residence on this voyage, James Batchelor researched physical systems and processes of 'knowing', with a particular focus on the relationship between empirical and theoretical understanding. His daily practices on the voyage included drawing, writing, filming, photographing, and dancing. He experimented within these mediums to source movement from and respond to environments both internal and external to the ship. These tasks worked outwards from the known body to digest and translate new sensory or conceptualised information.



Appendix 8 Media

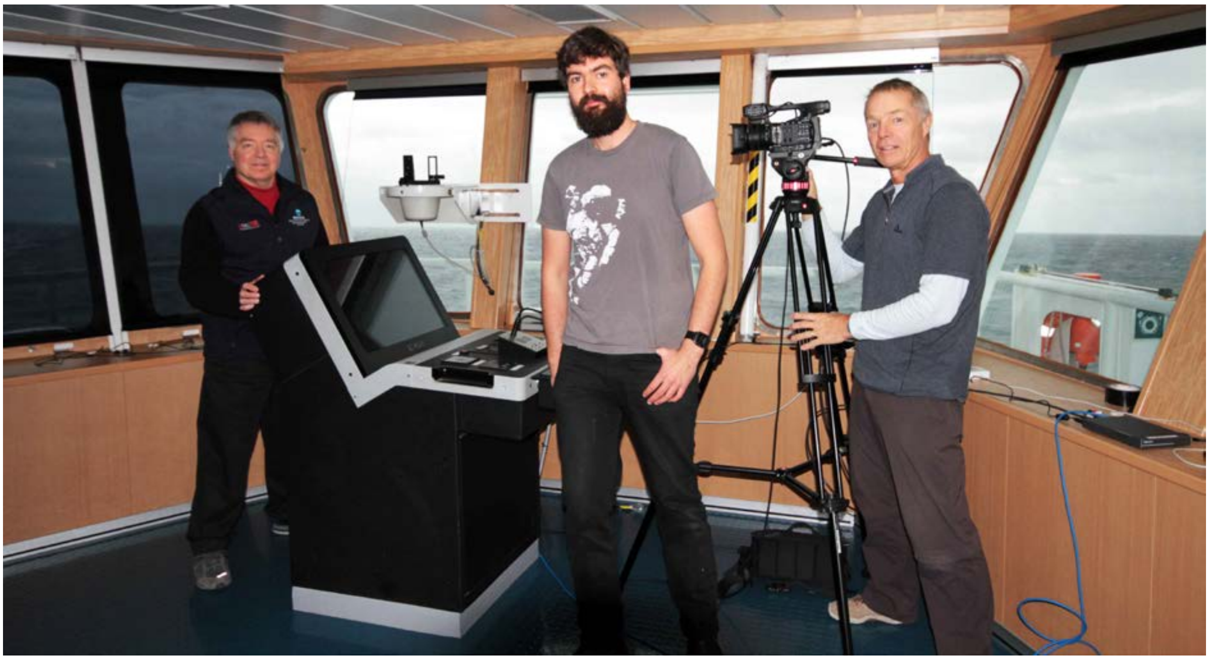
Peter Harmsen

A comprehensive visual record of this voyage, including physical operations, procedures, and various scientific undertakings, now exists. We also have a decent record of Heard and McDonald islands.

Prior to departure from Fremantle, on 7 January we conducted interviews with Prof Mike Coffin, Prof Richard Arculus, A/Prof Andrew Bowie, and Dr Tara Martin. These were sent to and used by the television stations ABC, Southern Cross, and WinTV in Hobart. Photographs were taken and used by the Sydney Morning Herald and others.

The eruption of Big Ben story was undoubtedly the media highlight of the voyage in terms of numbers. The vision and photographs we sent out on 31 January were used around the world, with coverage on ABC, BBC, The Mercury, The Statesman, Shanghai Daily, WebIndia, Daily Telegraph, Sydney Morning Herald, The Guardian, UK Daily Mail, Sky News, Australian Geographic, Mashable, The Hundu, International Business Times India, The Weather Network, Science Alert, and many others. The University of Tasmania (UTAS) Institute for Marine and Antarctic Studies (IMAS), CSIRO, and ABC posted the YouTube clip we sent out, attracting more than 190,000 views.

After successful testing of onboard equipment by Hugh Barker and Peter Harmsen on 12, 14, and 28 January, we conducted the first ever television live cross from RV *Investigator* to ABC News24 on 15 February. This was originally planned for 10 February, but was postponed by the ABC for unknown reasons. We sent eight minutes of overlay vision for this, which was used during the live interview with Prof Mike Coffin.



ABC live television interview. Left – Prof Mike Coffin, center – Hugh Barker, right – Peter Harmsen. Credit: Brett Muir.

In six installments, we provided approximately 45 minutes of vision to North America's Discovery Channel for a feature story on our voyage. The resulting story has aired on their Daily Planet science program and runs 4:42.

We prepared a five-minute compilation of vision that was available for media use on our return to Hobart on 27 February. A media call at IMAS attracted the television stations ABC and WinTV, who conducted interviews with Prof Mike Coffin, Prof Richard Arculus, and A/Prof Andrew Bowie.

Chief Scientist Prof Mike Coffin provided weekly blogs to IMAS and CSIRO with many photographs, and IMAS blogs used video, including an edited 3:30 story with A/Prof Andrew Bowie about iron levels in the Southern Ocean. Blogs about this voyage on the IMAS and CSIRO websites number about 20.

Per contract, a "one-second documentary" running 3:33 covering many aspects of the voyage was compiled. Supplementary to the contract, a voyage compilation titled "Private Investigations" running 16:17 was produced, mainly for voyage participants as opposed to media. [**Warning**: The latter compilation is not part of the contract, and should not be widely distributed, without prior consent of MNF/CSIRO. It contains commercial music that would be breach of copyright if used in any commercial sense.] Both documentaries were well received by the science and arts party.

All video and still photographs remain part of the onboard data set and are publicly available. Totals are:

- Video: ~10 hours of high definition sourced from seven different cameras.
- Stills: ~1,300 (stored) images sourced from six different cameras.