MNF Voyage Summary

Voyage #:	IN2020_V06		
Voyage title:	Probing the Australian-Pacific Plate Boundary: Macquarie Ridge in 3-D		
Mobilisation:	Hobart, Saturday 3 October – Thursday 8 October 2020		
Depart:	Hobart, 1308 Thursday, 8 October 2020		
Return:	Hobart, 0810 Tuesday, 3 November 2020		
Demobilisation:	Hobart, Tuesday, 3 November 2020		
Voyage Manager:	Megan Hartog	Contact details:	Megan.Hartog@csiro.au
Chief Scientist:	Prof Millard (Mike) F Coffin		
Affiliation:	Institute for Marine and Antarctic Studies, University of Tasmania	Contact details:	mike.coffin@utas.edu.au
Principal Investigators:	Prof Hrvoje Tkalčić[1], Dr Caroline Eakin[1], Prof Nick Rawlinson[2], Prof Joann Stock[3]		
Affiliation:	[1]RSES/Australian National University	Contact details:	hrvoje.tkalcic@anu.edu.au caroline.eakin@anu.edu.au
Affiliation:	[2]University of Cambridge	Contact details:	nr441@cam.ac.uk
Affiliation:	[3]California Institute of Technology	Contact details:	jstock@gps.caltech.edu

Voyage Summary

Objectives and brief narrative of voyage

Scientific objectives

The primary objectives of the voyage are to acquire passive seismological data that will enable us to:

1. Characterise the 3-D structure of the oceanic crust and sub-crustal lithosphere along the Macquarie Ridge Complex (MRC) with novel lithospheric seismic imaging. This includes teleseismic receiver function analysis, teleseismic and ambient noise tomography, joint inversion of receiver functions and ambient noise dispersion, shear wave splitting analysis, autocorrelation analysis, and enhancing of regional, teleseismic, and correlation wavefields through array seismology.
2. Describe the structural, thermal, and compositional nature of the central MRC by applying a range of seismic imaging techniques to identify velocity anomalies in the crust and mantle. This is possible because 2-D or 3-D images of velocity anomalies in the crust and mantle may be interpreted as structural, thermal, or compositional variations.

These seismological objectives will be addressed by PIs Tkalčić, Eakin, and Rawlinson with their respective research teams following instrument and data recovery planned for late 2021. To achieve the above objectives, we deployed 27 ocean bottom seismometers (OBSs) around Macquarie Island, to be recovered in late 2021.

The primary marine geophysical objectives of the voyage were to:

1. Define sites for OBS deployments in the vicinity of Macquarie Island using multibeam sonar and sub-bottom profiling data. Deployment parameters are tentatively in water depths ≥500 m and on gentle seafloor slopes, ideally flat, but not to exceed 30°. Sediment cover was preferred over bare igneous rock for OBS deployment. Existing data around Macquarie Island were not of sufficient quality to define deployment sites.
2. Characterise the neotectonics, structure, and stratigraphy of the active Australian-Pacific plate boundary in the vicinity of Macquarie Island using multibeam sonar (both bathymetry and backscatter), sub-bottom profiling, gravity, and magnetics data. These data will also provide critical information for baseline benthic habitat mapping.

PIs Coffin and Stock are leading efforts to address these marine geophysical objectives following completion of the mapping, sub-seafloor imaging, gravity, and magnetics program planned for late 2021.

CSIRO/MNF COVID-19 protocols prohibited the planned participation on the voyage of all international scientists, students, and technicians. These included California Institute of Technology Principal Investigator Prof Joann Stock, PhD student Krittanon Sirorattanakul, and undergraduate student Andrew Chan; University of Cambridge Dr Chuanchuan Lu and PhD students Conor Bacon and Omry Volk (all representing Principal Investigator Prof Nick Rawlinson); Institute of Geology & Geophysics/Chinese Academy of Sciences OBS technicians Yaoxing Hu and Yuan Wang, Université de la Réunion A/Prof Fabrice Fontaine, University of Zagreb Dr Marija Mustać, and College of the Atlantic ecologists Natasha Pastor and Rachel Rice.

Voyage objectives

We undertook multibeam sonar and sub-bottom profile data acquisition and interpretation in the Macquarie Island region to identify suitable sites for deployment of OBSs and deployed 27 OBSs (16 Australian Geophysical Observing System, or AGOS, and 11 Chinese Academy of Sciences, or CAS). Lost time was dealt with through reducing the size of the deployment survey area.
This project entails both marine geophysical data acquisition and deployment/retrieval of ocean bottom seismometers. In more detail, below we describe the methods utilised at sea.

Multibeam bathymetry/backscatter: we acquired multibeam/backscatter data in both the study area and during the transits. Water depths ranged from ~50 m to >5500 m, so the primary system was the EM122, complemented by the EM710 in water depths less than ~1000 m. Track orientation in the study area was along the strike of the Macquarie Ridge Complex, parallel to its axis, so as to maximise data acquisition efficiency and coverage. Near-real-time multibeam data was utilised to create maps to identify optimal locations for OBS deployments, for which flat seafloor or shallow seafloor slopes were required, and to identify the active fault(s) marking the boundary between the Australian and Pacific tectonic plates. High-resolution multibeam bathymetry/backscatter data had not been acquired previously in the study area. Available bathymetry was either low-resolution side-scan sonar/bathymetry (Massell et al., 2000) or extremely low-resolution bathymetry calculated from satellite altimeter data (Smith & Sandwell, 1997), insufficient for OBS deployment site selection or for identification of active plate boundary faults.

Sub-bottom profiling: we acquired SBP120 data continuously during multibeam/backscatter data acquisition. These near-real-time data contributed to identifying the best locations for OBS deployments (e.g., presence of shallow sediment) and active faults (e.g., offsets/deformation of shallow sediment). Sub-bottom profiling data had not been acquired previously from the study area.

Passive seismology recording: The ship's crew and OBS technicians intended to deploy 29 OBSs around Macquarie Island for a time interval of ~12 months. The pool of 17 three-component ocean bottom seismometers, a multi-million-dollar investment of AuScope, were available with 12 months of recording capacity (at a recording rate of 100 samples per second). Their acquisition was part of the Australian Geophysical Observing System (AGOS), a government initiative funded through the Education Investment Fund. The 12 Chinese Academy of Sciences (CAS) OBSs also have 12 months of recording capacity. The AGOS and CAS OBSs can be safely installed to maximum depths of 6000 and 5000 m, respectively, with the exception of two CAS OBSs that could only be safely installed to a maximum depth of 3000 m. For both types of instruments, slopes steeper than 30° had to be avoided. Actual field implementation depended on water depth, seafloor slope, and seafloor nature at each potential deployment location, taking into account current, wave, and wind vectors.

- **Array configuration:** We initially intended to use a logarithmic (three spiral arms) configuration in the southern section of the experiment and an X-shaped configuration in the northern part of the array. Smaller subsets of elements with favourable shape and element spacing were designed to improve the observational capacity in a particular frequency range. We had to redesign these configurations due to seafloor morphology and weather conditions. Although the implemented OBS deployment sites are quasi-spiral and quasi-X-shaped, they differ from the original indicative positions.

- **Earth imaging using passive seismology data:** Continuous waveform data in a digital format are being recorded over a time interval of approximately one year. During that time, typically >100 moderate to large magnitude earthquakes occur at different locations around the world. More precisely, over the last decade, Earth experienced an average of 15 M_w 7.0-8.0, 115 M_w 6.0-7.0, and ~1300 M_w 5.0-6.0 earthquakes annually. The elastic waves generated at earthquake loci propagate through the Earth's interior to the region of study and the ground motion gets recorded in the form of time series called seismograms. We will use these recordings to gain a better understanding of the Earth beneath the region of study.

Gravity: gravity data were acquired by the shipboard gravity meter during the entire voyage. Limited shipboard gravity data have been acquired in the study area; these data will help constrain the crustal and upper mantle structural objectives of the project.

Magnetics: magnetics data were acquired by the towed magnetometer during all transits and many multibeam/sub-bottom profiling lines. Limited shipboard magnetics data have been acquired in the study area; these data will help constrain the crustal and upper mantle structural objectives of the project.

ADCP: Multibeam and EK80 data took priority and precedence over ADCP data during multibeam/sub-bottom profile data acquisition, when ADCPs were turned off. Current information was required for OBS deployments, so ADCPs were turned on for these.

Results

Multibeam bathymetry/backscatter: The EM122 and EM710 multibeam echosounders performed well throughout the voyage, enabling mapping of ~57,737 km^2 of seafloor, in water depths ranging from ~36.5 to ~5,530 m (Appendix C: Figures 1-4). Due to waiting on weather for 39% of the voyage's time in the central MRC study area, far exceeding the contingency time included in the voyage application, we were unable to complete mapping of ~1,000 km^2 of seafloor along the central MRC around Macquarie Island, mostly in water depths <1,500 m. Completion of this mapping is estimated to require ~82 hours, of ~3.5 days, and should be undertaken during the MNF voyage planned for late 2021 when the 27 OBSs will be retrieved. Initial multibeam bathymetry/backscatter data from this voyage have already been provided to Parks Australia and the Tasmanian Parks and Wildlife Service (Appendix C: Figures 5, 6).

Sub-bottom profiling: The SBP120 sub-bottom profiler yielded high quality data on sedimented, relatively flat seafloor. It did not perform well on the mostly steep, rough, and bare rock seafloor of the central MRC. We acquired ~5,909 line-km of SBP120 data (Appendix C: Figure 7).

Passive seismology recording: A total of 27 OBSs were successfully deployed on the seafloor along the central MRC centered on Macquarie Island in water depths ranging from 520 m to 5517 m (Appendix C: Figures 3, 4). All but one successful deployment involved releasing the OBS at the sea surface and triangulating its position from the ship. A near-seafloor release method employing the CTD wire and an ultra-short baseline (USBL) acoustic positioning system on the wire above the OBS was attempted with the first AGOS and the first CAS OBS deployments, but only worked successfully with the first CAS OBS. Failures of components connecting the OBSs to the wire compelled abandonment of the near-seafloor release method after the first two attempts. One AGOS OBS released its ballast prematurely, was recovered and re-ballasted, and was successfully re-deployed. Two OBSs – one AGOS and one CAS – of the original total pool of 29 instruments were lost during the voyage. The lost AGOS OBS never made it to the 5,000+ m seafloor; instead, it became stuck at ~2,350 m water depth, and did not respond to multiple commands for it to surface. The lost CAS OBS released its ballast prematurely and surfaced; however, when attempting to retrieve it, its lifting bale failed, and no other means to recover it were available on the ship. Both OBSs were lost within the Macquarie Island Marine Park; their losses were reported to the Director of Parks' Marine Compliance Duty Officer.

Gravity: gravity data were acquired by the shipboard gravity meter during the entire voyage, for a total of ~8,308 line-km (Appendix C: Figure 8). Limited shipboard gravity data have been acquired previously in the study area; these new data will help constrain the crustal and upper mantle structural objectives of the project.

Magnetics: magnetics data were acquired by the towed magnetometer during all transits and many multibeam/sub-bottom profiling lines, for a total of ~4,916 line-km (Appendix C: Figure 9). Limited shipboard magnetics data had been acquired previously in the study area; these new data will help constrain the tectonic, as well as the crustal and upper mantle structural objectives of the project.

ADCP: Multibeam and EK80 data took priority and precedence over ADCP data during multibeam/sub-bottom profile data acquisition, when ADCPs were turned off. Current information was required for OBS deployments, so ADCPs were turned on for these. However, ADCP data were only available for the upper few hundred meters of the water column, and in some instances, current vectors in the upper water column sensed by the ADCPs opposed those deeper in the water column. Hence ADCP data proved not very useful at deployment sites in water depths >1000 m.

Voyage narrative

RV *Investigator* departed from Hobart on 8 October 2020, following COVID-19 testing of the entire shipboard complement on 6 October and ensuing shipboard isolation awaiting test results (all negative). Heavy weather the night of 8 October forced the ship to alter course and reduce speed, delaying our arrival at the Macquarie Island study area on 11 October by ~8 hours. On the transit from Hobart to Macquarie Island, multibeam bathymetry/backscatter, sub-bottom profiler, gravity, magnetics, and XBT data were acquired.

Once in the study area, the work program of marine geophysical data acquisition, OBS site selection based thereon, and OBS deployment progressed in a generally clockwise pattern around Macquarie Island, starting northeast of the island. Between 11 and 30 October, ~24,959 km^2 of the seafloor were mapped using the EM122 (Appendix C: Figures 1-6), ~6,406 km^2 of the seafloor were mapped using the EM710 (Appendix C: Figures 1-6), ~3,022 line-km of the shallow sub-seafloor were imaged with the SBP120 (Appendix C: Figure 7), 29 OBSs were deployed, ~5,063 line-km of gravity data were acquired (Appendix C: Figure 8), ~2,037 line-km of magnetic data were collected (Appendix C: Figure 9), and 13 XBTs were successfully deployed. As noted above, two OBSs – one AGOS and one CAS – were lost, leaving a total of 27 OBSs on the seafloor for recovery planned in late 2021. Furthermore, one AGOS OBS was deployed, recovered, and redeployed.

Very rough (4-6 m) to high (6-9 m) sea states accompanied by winds as strong as Beaufort Force 11 (>56 kts) negatively impacted our work program in the study area, which lasted from 11 to 30 October. Of the total 19 days in the study area, 7.4 (39%) were spent waiting on weather, either in the lee of Macquarie Island or hove-to. To help compensate for this loss of productive work time, the MNF granted IN2020_V06 two additional days of sea time.

On 29 October, on request of Australian Antarctic Division (AAD), two expeditioners from the AAD Macquarie Island Station boarded RV *Investigator* for compassionate transfer to Hobart. Total time for these operations was approximately six hours.

RV *Investigator* departed the central MRC study area on 31 October, arriving in Hobart on 3 November.

Outreach, education and communications activities

The University of Tasmania and Australian National University scientists, students, and technicians participated in various outreach, education and communications activities over the course of the voyage. In terms of outreach and communication, prior to the voyage, *The National Tribune* published a relevant piece on 7 October (https://www.nationaltribune.com.au/voyage-to-unlock-macquarie-island-s-geological-secrets/), as did *The Mercury* on 8 October (https://www.themercury.com.au/news/tasmania/voyage-to-study-sea-floor-and-boost-earthquake-and-tsunami-monitoring/news-story/59be8c737a1b11ac45cced02aabb36a9). Sarah Maunder of SBS interviewed Chief Scientist Prof Mike Coffin, Lead Principal Investigator Prof Hrvoje Tkalčić, and Principal Investigator Dr Caroline Eakin on 8 October (https://www.sbs.com.au/news/audiotrack/researchers-set-macquarie-island-after-covid-delay). During the voyage, Prof Coffin wrote four weekly reports and Honours student Yun Fann Toh wrote one blog, all of which were posted on the IMAS website (https://www.imas.utas.edu.au/news/news-items/voyage-to-unlock-macquarie-islands-geological-secrets). Prof Tkalčić authored eight blogs posted by the ANU Research School of Earth Sciences over the course of the voyage on FaceBook (https://www.facebook.com/anuearthsciences/), Geo-Down-Under (https://geo-down-under.geoscience.education/), and numerous Croatian mass media. The voyage also featured on AuScope news (https://www.auscope.org.au/news) and in Canberra's RiotACT (https://the-riotact.com/anu-researchers-on-voyage-to-discover-the-earths-core/41192/ and https://the-riotact.com/dark-and-stormy-mission-at-sea-has-research-team-going-to-great-depths/421267). PhD student Thuany Patricia Costa de Lima wrote two voyage blogs posted on Wordpress (https://oncirculation.wordpress.com/2020/10/29/southern-ocean-part-i/ and https://oncirculation.wordpress.com/2020/11/05/southern-ocean-part-ii/). Upon conclusion of the voyage, Prof Coffin was interviewed by Helen Shield on ABC Radio Hobart on 4 November.

Onboard educational activities encompassed OBS training for senior scientist Prof Hrvoje Tkalčić; early-career scientists Dr Caroline Eakin, Dr Xiaolong Ma, and Dr Thanh-Son Pham; PhD students Thuany Patricia Costa de Lima and Sheng Wang; and technicians Rajesh Erigela, Andrew Latimore, and Dr Robert Pickle. They also encompassed marine geophysical training for Honours student Yun Fann Toh. A shipboard series of 18 seminars by scientists, students, technicians (both OBS and MNF), and ship's crew served to share knowledge and build camaraderie among the entire ship's complement. The OBS training will be employed on the MNF OBS recovery voyage planned for late 2021 as well as OBS voyages further in the future. The marine geophysical training is helping guide career aspirations for Yun Fann Toh.

Prof Hrvoje Tkalčić and Dr Caroline Eakin had not sailed on RV *Investigator* previously, and IN2020_V06 was Prof Tkalčić's first and Dr Eakin's second research voyage. Having now completed a voyage on RV *Investigator*, they now qualify to serve as Chief Scientist on future voyages.

CSIRO/MNF COVID-19 protocols prohibited the planned participation on the voyage of two artists, soprano Allison Bell (http://allisonbellsoprano.com/) and photographer Zan Wimberley (http://www.zanwimberley.com/). Both are interested in future art-science collaborations on RV *Investigator* voyages.

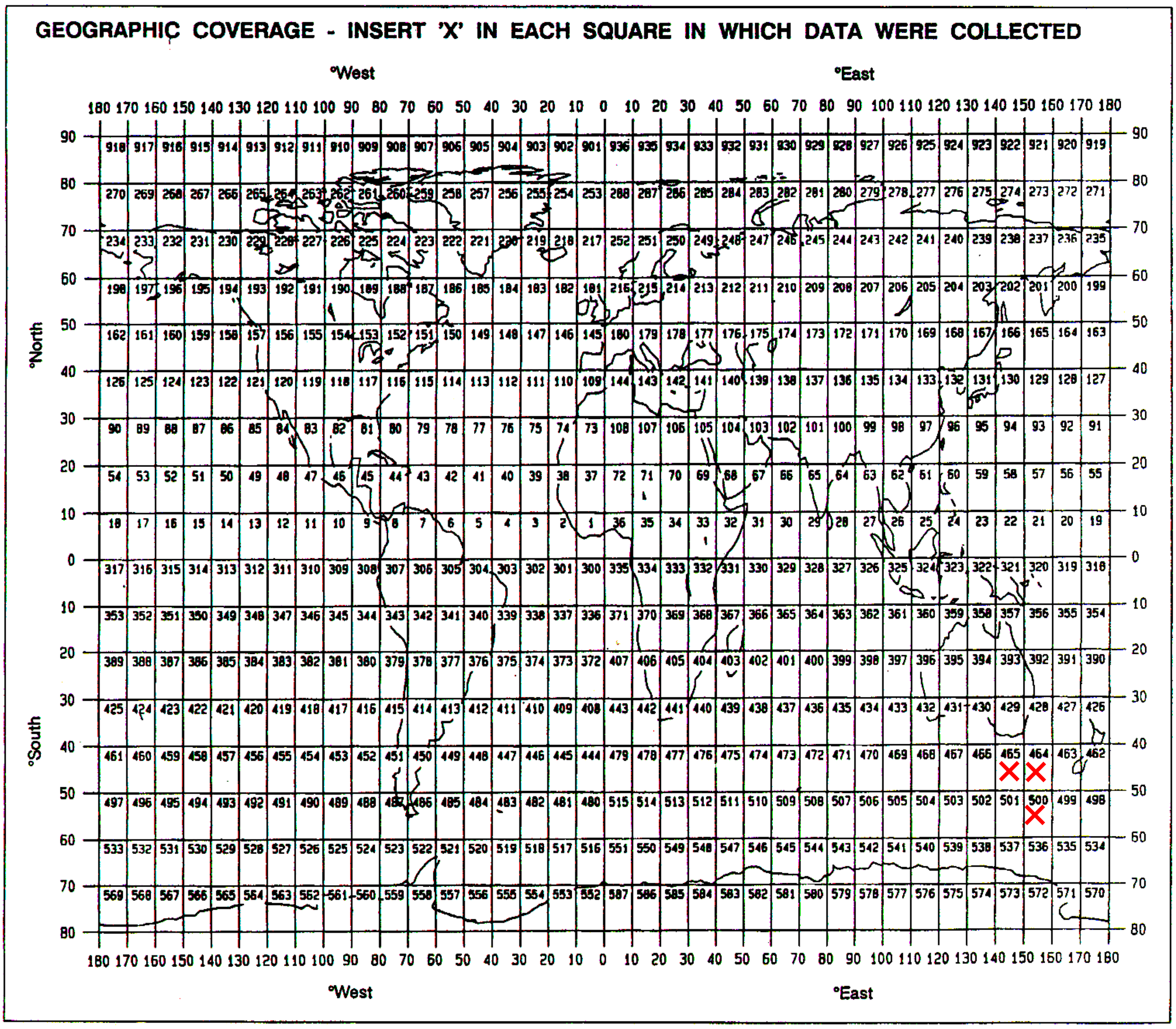
Summary

The voyage's main successes were mapping much of the seafloor and deploying the full complement of 29 OBSs along the central MRC near Macquarie Island, albeit losing two of the OBSs following their deployment. The area around Macquarie Island is arguably among the most challenging locations in the global ocean for an OBS experiment given its extreme topography, strong currents, high winds, and high seas. This was the first time the AGOS OBSs and most of the CAS OBSs had been deployed outside relatively benign tropical latitudes, and the first time any OBSs had been operationally deployed from RV *Investigator*. At the request of the science party, the voyage was rescheduled in an effort to overcome challenges associated with getting international technicians and equipment to Hobart for the voyage, given COVID-19 restrictions. This request was supported by the MNF, however a shift of voyage dates outside of the optimal November-March Southern Ocean weather window may have contributed to 39% of operational time in the study area being spent waiting on the weather, perhaps a downtime record for an RV *Investigator* voyage. An MNF extension of the voyage by two days partially compensated for this loss, but approximately 3.5 days of shiptime will be needed to complete the original seafloor mapping objectives. COVID-19 protocols reduced science party numbers from 28 to 11, including exclusion of all international participants and two artists. Discussions around these possible limits on voyage personnel were held throughout the final 4-5 months of voyage planning, with a final confirmation of restrictions approximately two months prior to the voyage. COVID-19 restrictions unfortunately negatively impacted scientific and technical interactions and synergies during the voyage, as well as the professional and personal plans of those excluded. It also severely limited research training opportunities and eliminated art-science collaborations. Overall, however, the voyage was able to achieve most of its primary objectives despite major weather and COVID-19 challenges.

The success of the voyage may be attributed to the skills, experience, and flexibility of the ship's crew, MNF staff, and the science party, and their ability to work together in all circumstances.

Recovery of the 27 OBSs, following their one-year deployment, and completion of seafloor mapping along the central MRC near Macquarie Island is anticipated for late 2021.

Marsden Squares



Moorings, bottom-mounted gear and drifting systems

Item Name, Identifier (e.g. serial number)	Principal Investigator (see Title Page)	APPROXIMATE POSITION (as degrees, decimal minutes)						DATA TYPE enter code(s) from list in Appendix A	DESCRIPTION
		LATITUDE			LONGITUDE				Identify, as appropriate, the nature of the instrumentation, the parameters measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any site identifiers.
		deg	min	N/S	deg	min	E/W		
MRO04 CAS	Prof Nick Rawlinson	54	36.4 980 1	S	159	10.3 755 7	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 4627 m, deployed, 14-Oct-20
MRO08 AGOS	Prof Hvroje Tkalčić	54	35.7 56	S	159	16.4 28	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5449 m, deployed, 14-Oct-20
MRO03 CAS	Prof Nick Rawlinson	54	19.4 12	S	159	10.3 69	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 3636 m, deployed, 16-Oct-20
MRO23 CAS	Prof Nick Rawlinson	54	48.6 5	S	158	41.0 63	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 976 m, deployed, 18-Oct-20
MRO24 CAS	Prof Nick Rawlinson	54	39.6 38	S	159	42.5 42	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 883 m, deployed, 18-Oct-20
MRO13 CAS	Prof Nick Rawlinson	55	07.8 474	S	158	52.1 838	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 3744 m, deployed, 19-Oct-20

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		LATITUDE			LONGITUDE				**Identify, as appropriate, the nature of the instrumentation, the parameters measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any site identifiers.**
		deg	min	N/S	deg	min	E/W		
MRO20 CAS	Prof Nick Rawlinson	55	20.012	S	158	33.05	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 2391 m, deployed, 22-Oct-20
MRO15 AGOS	Prof Hvroje Tkalčić	55	12.262	S	158	50.629	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 3647 m, deployed, 22-Oct-20
MRO17 AGOS	Prof Hvroje Tkalčić	55	20.3898	S	158	56.4156	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5399 m, deployed, 22-Oct-20
MRO30 AGOS	Prof Hvroje Tkalčić	55	28.0116	S	158	12.1134	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5032 m, deployed, 22-Oct-20
MRO16 AGOS	Prof Hvroje Tkalčić	55	14.6	S	159	10.632	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5211 m, deployed, 23-Oct-20
MRO28 AGOS	Prof Hvroje Tkalčić	54	56.0616	S	159	14.5728	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5275 m, deployed, 23-Oct-20
MRO27 AGOS	Prof Hvroje Tkalčić	55	04.5996	S	159	12.1032	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5517 m, deployed, 23-Oct-20
MRO26 AGOS	Prof Hvroje Tkalčić	55	08.895	S	159	04.8168	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5057 m, deployed, 24-Oct-20

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		deg	min	N/S	deg	min	E/W		
MRO10 AGOS	Prof Hvroje Tkalčić	54	44.466	S	159	10.025	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 5363 m, deployed, 24-Oct-20
MRO21 AGOS	Prof Hvroje Tkalčić	54	49.8732	S	159	21.6408	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 4785 m, deployed, 24-Oct-20
MRO12 CAS	Prof Nick Rawlinson	55	02.215788	S	158	51.1878	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 2437 m, deployed, 26-Oct-20
MRO11 CAS	Prof Nick Rawlinson	54	57.955	S	158	38.637	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 896 m, deployed, 26-Oct-20
MRO14 AGOS	Prof Hvroje Tkalčić	54	57.868	S	158	25.145	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 2651 m, deployed, 26-Oct-20
MRO19 AGOS	Prof Hvroje Tkalčić	55	18.8748	S	158	08.1078	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 4285 m, deployed, 26-Oct-20
MRO18 AGOS	Prof Hvroje Tkalčić	55	11.8092	S	158	11.0592	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 4436 m, deployed, 27-Oct-20
MRO01 AGOS	Prof Hvroje Tkalčić	54	05.2506	S	159	22.2354	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 4996 m, deployed, 28-Oct-20

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		LATITUDE			LONGITUDE				**Identify, as appropriate, the nature of the instrumentation, the parameters measured, the number of instruments and their depths, whether deployed and/or recovered, dates of deployments and/or recovery, and any site identifiers.**
		deg	min	N/S	deg	min	E/W		
MRO06 CAS	Prof Nick Rawlinson	54	24.3 228	S	158	50.9 058	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 520 m, deployed, 29-Oct-20
MRO05 AGOS	Prof Hvroje Tkalčić	54	24.2 946	S	158	50.9 652	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 521 m, deployed, 29-Oct-20
MRO07 CAS	Prof Nick Rawlinson	54	16.5 558	S	158	42.1 836	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 3006 m, deployed, 29-Oct-20
MRO25 AGOS	Prof Hvroje Tkalčić	54	42.4 782	S	158	15.6 444	E	G72	Ocean bottom seismometer (Güralp Libre), 3-component seismic phases of earthquakes, 4140 m, deployed, 29-Oct-20
MRO22 CAS	Prof Nick Rawlinson	54	05.7 354	S	158	31.6 566	E	G72	Ocean bottom seismometer (Chinese Academy of Sciences G60), 3-component seismic phases of earthquakes, 3966 m, deployed, 29-Oct-20

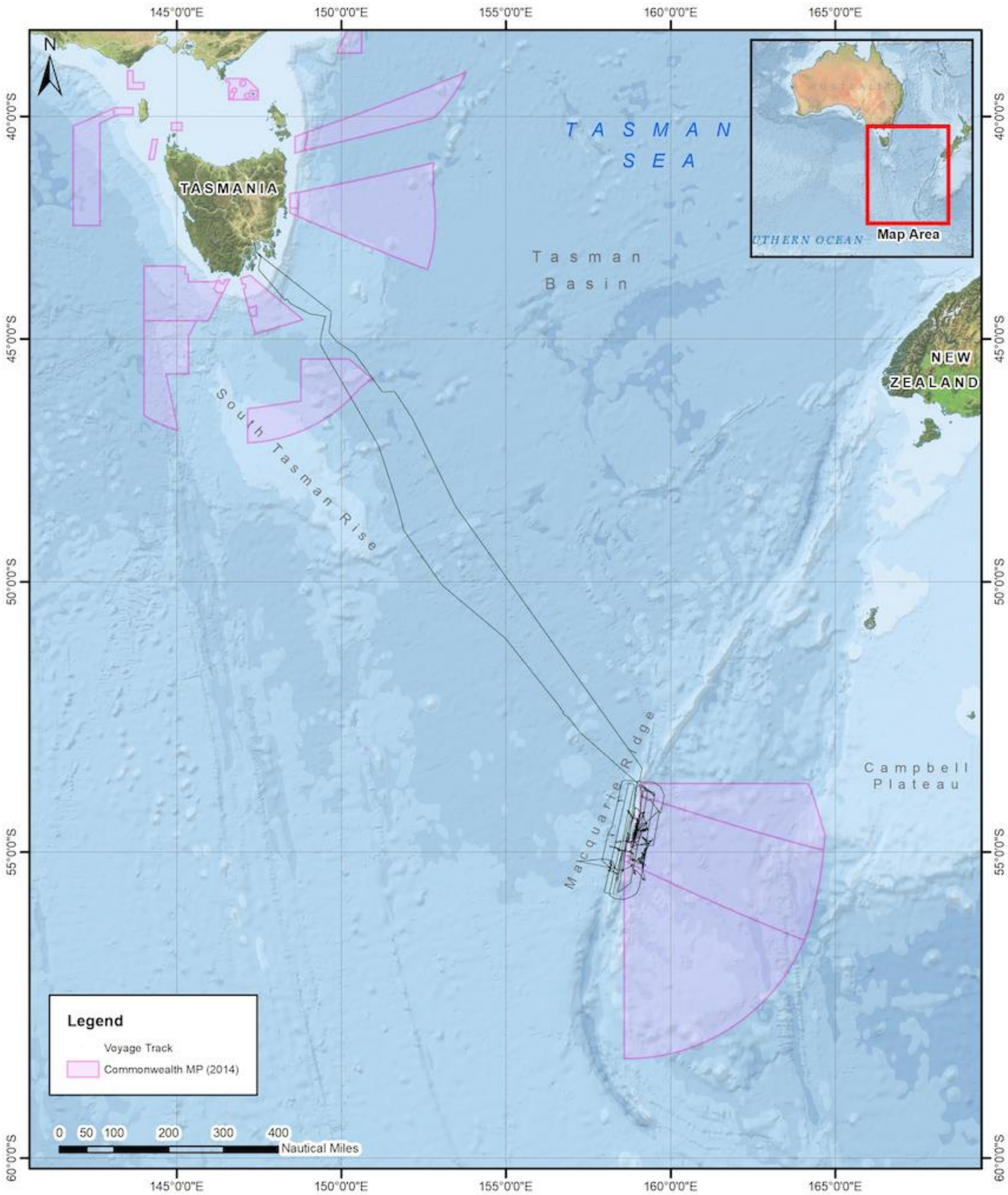
[n.b. Two OBSs were irretrievably lost, one AGOS and one CAS. The AGOS OBS never reached the bottom, and appeared to be stuck at ~2300 m in the water column. The CAS OBS lost its ballast and returned to the surface, where its lifting hook broke during retrieval. The ship had no further equipment (e.g., net) to retrieve it, and it was abandoned. In addition, one AGOS lost its ballast following deployment and returned to the surface. It was successfully recovered and redeployed.]

Summary of data and samples collected

Item Name, Identifier (e.g. serial number)	Principal Investigator (see Title Page)	NO (see above)	UNITS (see above)	DATA TYPE Enter code(s) from list in Appendix A	DESCRIPTION Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate e.g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
EM122	Coffin		~24,958.8 km^2 / ~5,208.44 line-km (study area) ~32,777.7 km^2 / ~1,475.78 line-km (transits)	G74	Kongsberg/Simrad EM122 12 kHz multibeam echosounder
EM710	Coffin		~6,406 km^2 / ~677.46 line-km (study area) ~19.406 km^2 / ~74.47 line-km (transits)	G74	Kongsberg/Simrad EM710 multibeam echosounder (70-100 kHz)
EK80	Coffin		~3,472.1 line-km (study area) ~3,002.2 line-km (transits)	G73	Simrad EK80 multi-frequency split-beam echosounder (10-500 kHz)

Item Name, Identifier (e.g. serial number)	Principal Investigator (see Title Page)	NO (see above)	UNITS (see above)	DATA TYPE Enter code(s) from list in Appendix A	**DESCRIPTION** Identify, as appropriate, the nature of the data and of the instrumentation/sampling gear and list the parameters measured. Include any supplementary information that may be appropriate e.g. vertical or horizontal profiles, depth horizons, continuous recording or discrete samples, etc. For samples taken for later analysis on shore, an indication should be given of the type of analysis planned, i.e. the purpose for which the samples were taken.
SBP120	Coffin		~3,021.8 line-km (study area) ~2,887.1 line-km (transits)	G75	Kongsberg SBP120 sub-bottom profiler (2-8 and 12 kHz)
XBT	Coffin	16 successful casts [23 total casts]		H13	Lockheed Martin Sippican Deep Blue (760 m)
ADCP	Coffin	29 stations		D71	75 kHz / 150 kHz Acoustic Doppler Current Profiler
Gravity	Coffin		~5,062.8 line-km (study area) ~3,245.6 line-km (transits)	G27	MicroG Lacoste Air-Sea II
Magnetics	Coffin		~2,037.058 line-km (study area) ~2,878.88 line-km (transits)	G28	Marine Magnetics SeaSPY2 magnetometer

Track Chart



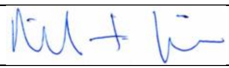
IN2020_V06 track map. Commonwealth marine parks indicated in pink. Inset shows large map area outlined in red.

Acknowledgements

We thank Master Michael Watson, Chief Officer Tom Watson, Chief Engineer Genna Gervasiev, CIR Jono Lumb, Chief Caterer Alan Martin & his team, and the rest of RV *Investigator*'s able officers, engineers, and crew for their crucial contributions to the successful outcomes of IN2020_V06. We are grateful to Voyage Manager Megan Hartog, Deputy Voyage Manager Max McGuire, Richard Atkinson, Hugh Barker, Craig Davey, Trevor Goodwin, Francisco Navidad, Aaron Tyndall, Phil van den

Bossche for their outstanding support during the voyage. We thank Joann Stock, Nick Rawlinson, and Tara Martin for their strong shoreside support throughout the voyage. We appreciate the assistance of Noel Carmichael and Cath Samson in obtaining the environmental permits necessary to conduct this research within the Tasmanian Macquarie Island Nature Reserve – Marine Area and Commonwealth Macquarie Island Marine Park, respectively. This research is supported by a grant of sea time on RV *Investigator* from Australia's Marine National Facility (27 days), by Australian Research Council grant DP200101854 ($626,000), by Natural Environmental Research Council (UK) grant NE/T000082/1 (£495,707), the Australian National Seismic Imaging Resource/AuScope, the Australian National University ($552,000), the University of Cambridge ($150,000), the University of Tasmania ($142,000), and the California Institute of Technology ($96,000).

Signature

Your name:	Millard (Mike) F Coffin
Title:	Chief Scientist
Signature:	
Date:	29 January 2021

Appendix A – CSR/ROSCOP Parameter Codes

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

	PHYSICAL OCEANOGRAPHY
H71	Surface measurements underway (T,S)
H13	Bathythermograph
H09	Water bottle stations
H10	CTD stations
H11	Subsurface measurements underway (T,S)
H72	Thermistor chain
H16	Transparency (eg transmissometer)
H17	Optics (eg underwater light levels)
H73	Geochemical tracers (eg freons)
D01	Current meters
D71	Current profiler (eg ADCP)
D03	Currents measured from ship drift
D04	GEK
D05	Surface drifters/drifting buoys
D06	Neutrally buoyant floats
D09	Sea level (incl. Bottom pressure & inverted echosounder)
D72	Instrumented wave measurements
D90	Other physical oceanographic measurements

	MARINE BIOLOGY/FISHERIES
B01	Primary productivity
B02	Phytoplankton pigments (eg chlorophyll, fluorescence)
B71	Particulate organic matter (inc POC, PON)
B06	Dissolved organic matter (inc DOC)
B72	Biochemical measurements (eg lipids, amino acids)
B73	Sediment traps
B08	Phytoplankton
B09	Zooplankton
B03	Seston
B10	Neuston
B11	Nekton
B13	Eggs & larvae
B07	Pelagic bacteria/micro-organisms
B16	Benthic bacteria/micro-organisms
B17	Phytobenthos
B18	Zoobenthos
B25	Birds
B26	Mammals & reptiles
B14	Pelagic fish
B19	Demersal fish
B20	Molluscs
B21	Crustaceans
B28	Acoustic reflection on marine organisms
B37	Taggings
B64	Gear research
B65	Exploratory fishing
B90	Other biological/fisheries measurements

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

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

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

Appendix B – Photographs

RV *Investigator* at the end of the rainbow pre-departure in Hobart. Credit: Mike Coffin, IMAS/UTAS.

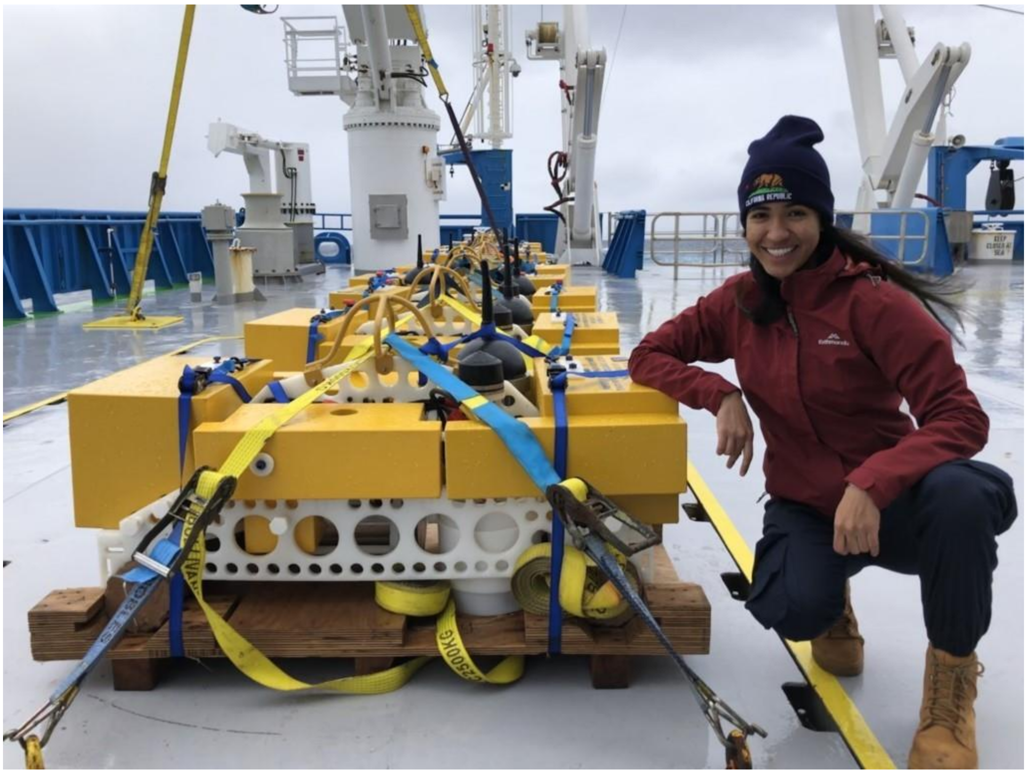
The shipboard science party departing Hobart. Credit: Megan Hartog, MNF/CSIRO.

IN2020_V06 Principal Investigators (from left to right) Dr Caroline Eakin, Prof Hrvoje Tkalčić, and Prof Mike Coffin convene to discuss the plan for OBS deployments. Credit: Yun Fann Toh, IMAS/UTAS.

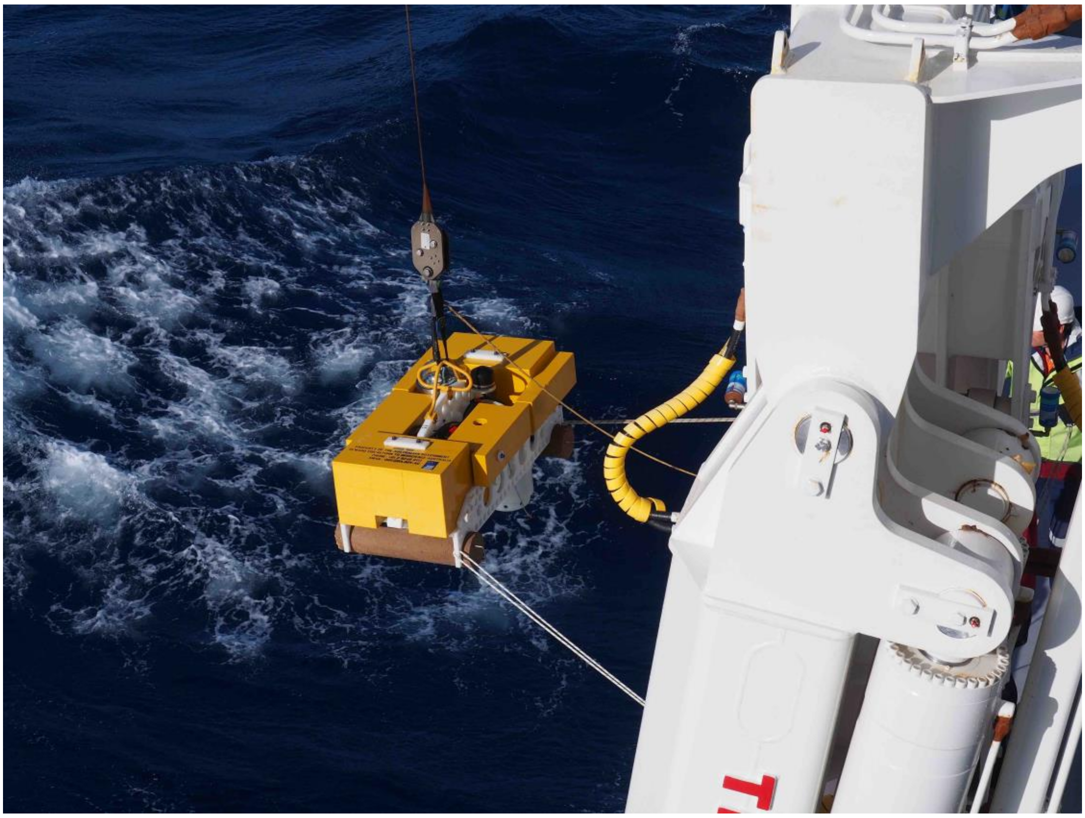
Scientists, students, and support staff on the bow of RV *Investigator*. MCQ3D: Macquarie Ridge in 3-D. Credit: Kristian Webster, ASP.

Australian Geophysical Observing System (AGOS) ocean bottom seismometers (OBSs), with Macquarie Island in the background. Credit: Mike Watson, ASP.

Preparing Australian Geophysical Observing System (AGOS) ocean bottom seismometers (OBS) for deployment, with RSES/ANU Dr Xiaolong Ma (left) and Andrew Latimore (right). Credit: Hrvoje Tkalić, RSES/ANU.



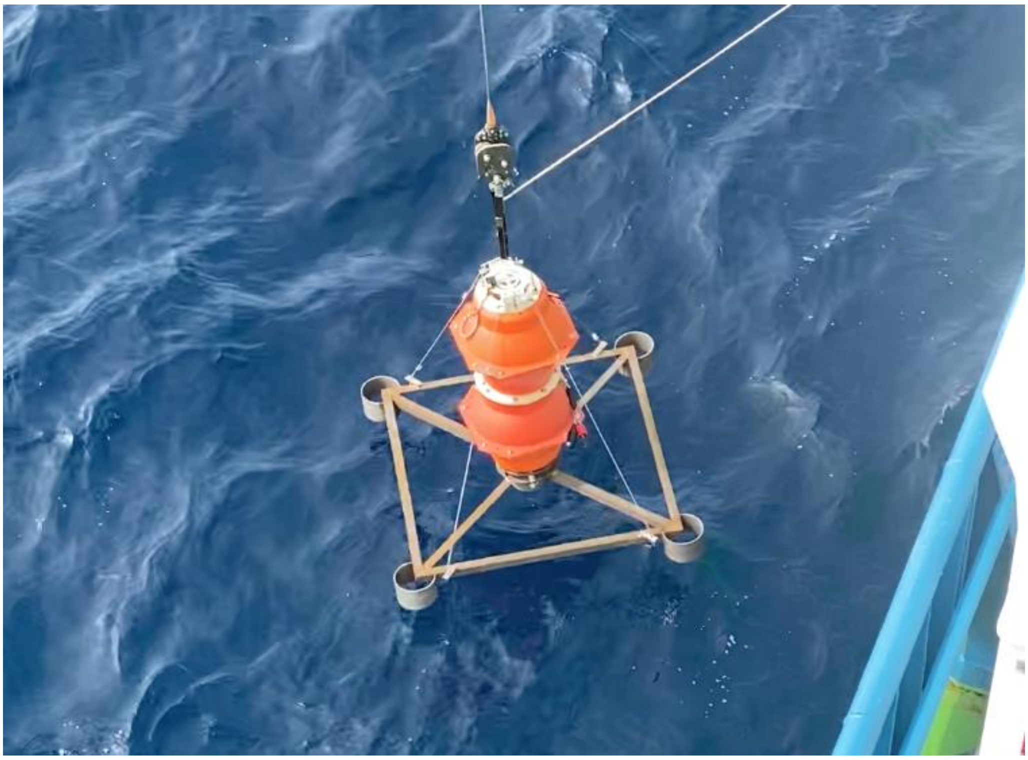
Australian Geophysical Observing System (AGOS) ocean bottom seismometers (OBSs), with RSES/ANU PhD student Thuany Patricia Costa de Lima. Credit: Xiaolong Ma, RSES/ANU.



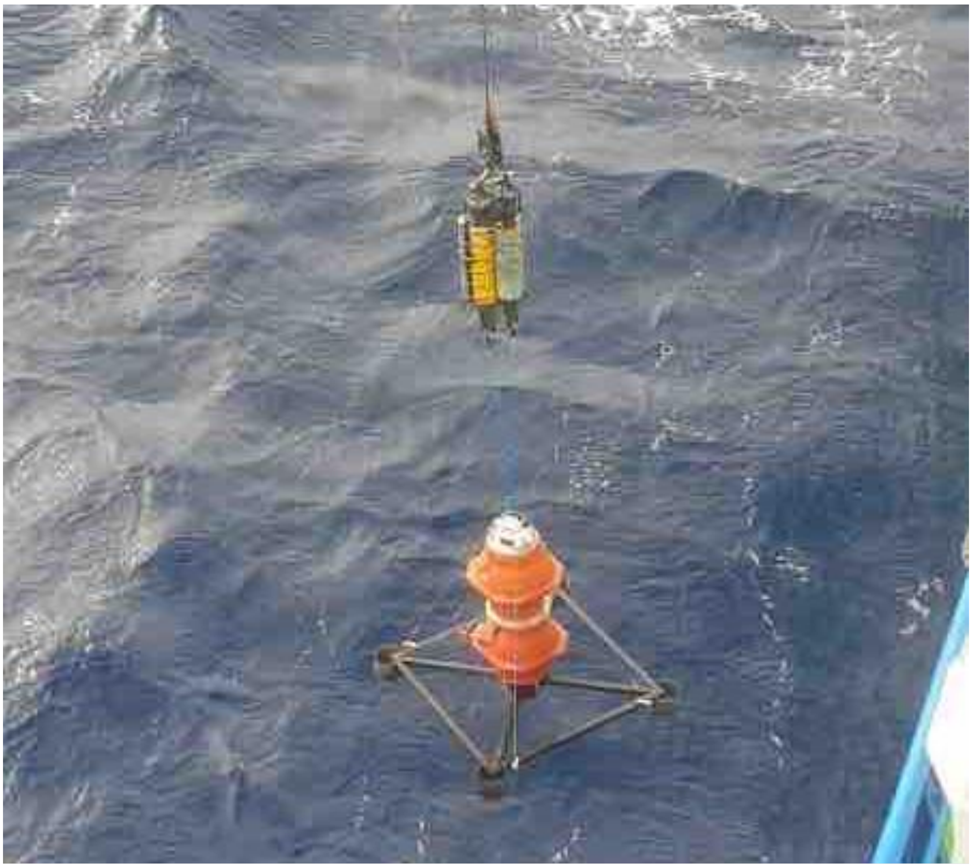
Surface deployment of Australian Geophysical Observing System (AGOS) ocean bottom seismometer (OBS). Credit: Richard Atkinson, MNF/CSIRO.

Near-bottom deployment of Australian Geophysical Observing System (AGOS) ocean bottom seismometer (OBS), with ultra-short baseline (USBL) acoustic positioning system. Credit: Hrvoje Tkalčić, RSES/ANU.

Unpacking, assembling, calibrating, and testing Chinese Academy of Sciences (CAS) ocean bottom seismometers (OBSs) immediately prior to the voyage, with Institute of Geology & Geophysics, Chinese Academy of Sciences Yuan Wang (left) and IMAS/UTAS PhD student Jiale Lou. Credit: Mike Coffin, IMAS/UTAS.



Surface deployment of Chinese Academy of Sciences (CAS) ocean bottom seismometer (OBS). Credit: Mike Coffin, IMAS/UTAS.



Near-bottom deployment of Chinese Academy of Sciences (CAS) ocean bottom seismometer (OBS), with ultra-short baseline (USBL) acoustic positioning system. Credit: Mike Watson, ASP.

Attempting to recover Chinese Academy of Sciences (CAS) ocean bottom seismometer (OBS). Credit: Mike Coffin, IMAS/UTAS.

RSES/ANU, MNF, and IMAS/UTAS personnel at Buckles Bay, Macquarie Island, with AAD Macquarie Island Research Station in the background. Credit: Francisco Navidad, MNF/CSIRO.

AAD rigid inflatable boats (RIBs) executing personnel and material transfer with RV *Investigator*, Buckles Bay, Macquarie Island. Credit: William Seal, AAD.

RV *Investigator* departing Buckles Bay, Macquarie Island. Credit: Scott McCartney, AAD.

Chocoholic masterpiece by the catering team commemorating Chief Scientist's 500th day on the Southern Ocean. Credit: Mike Coffin, IMAS/UTAS.

Appendix C – Maps

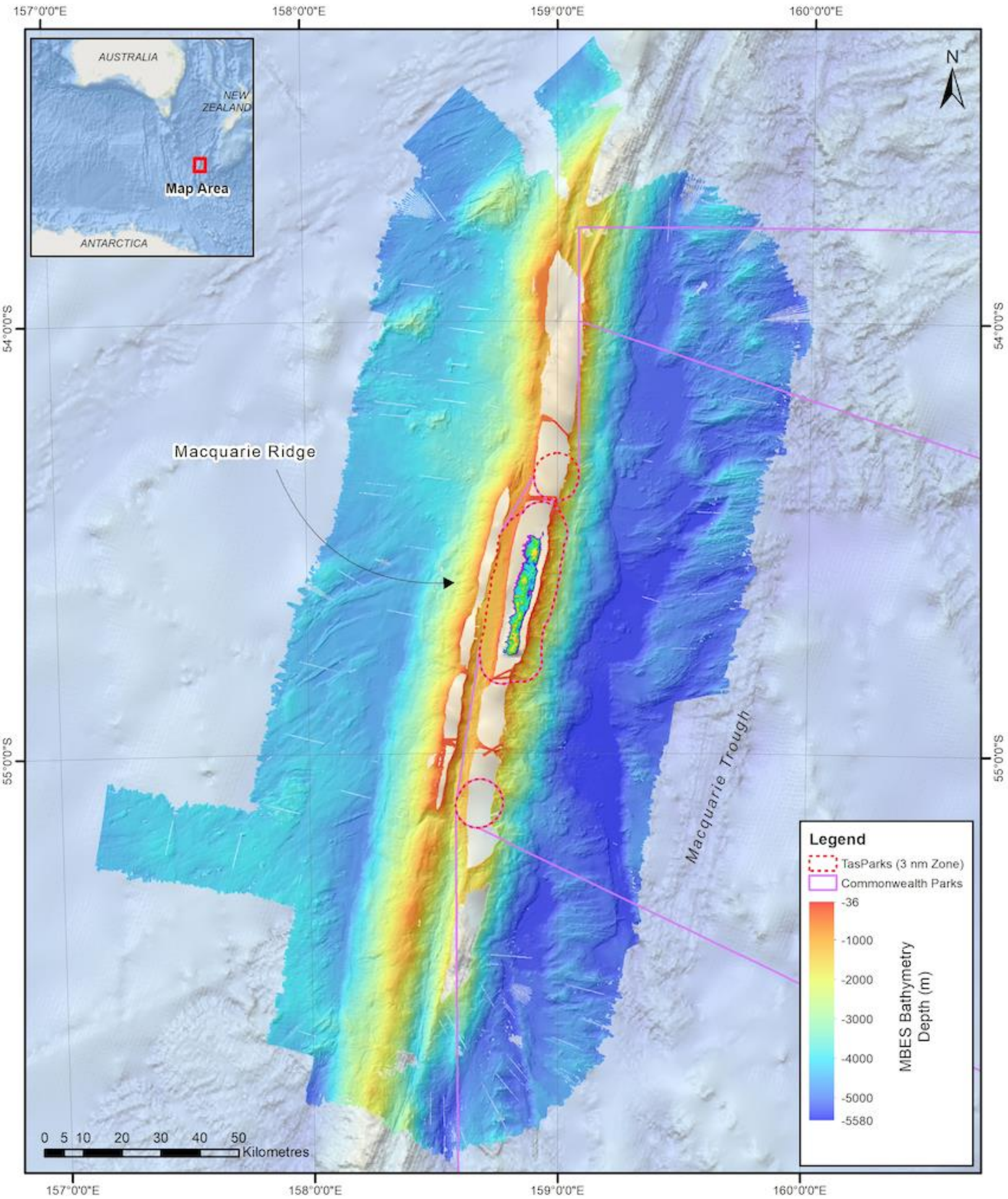


Figure 1. New IN2020_V06 multibeam bathymetry map. Tasmanian Macquarie Island Nature Reserve – Marine Area and Commonwealth Macquarie Island Marine Park outlined, respectively, in dashed red and solid pink lines. Tan along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

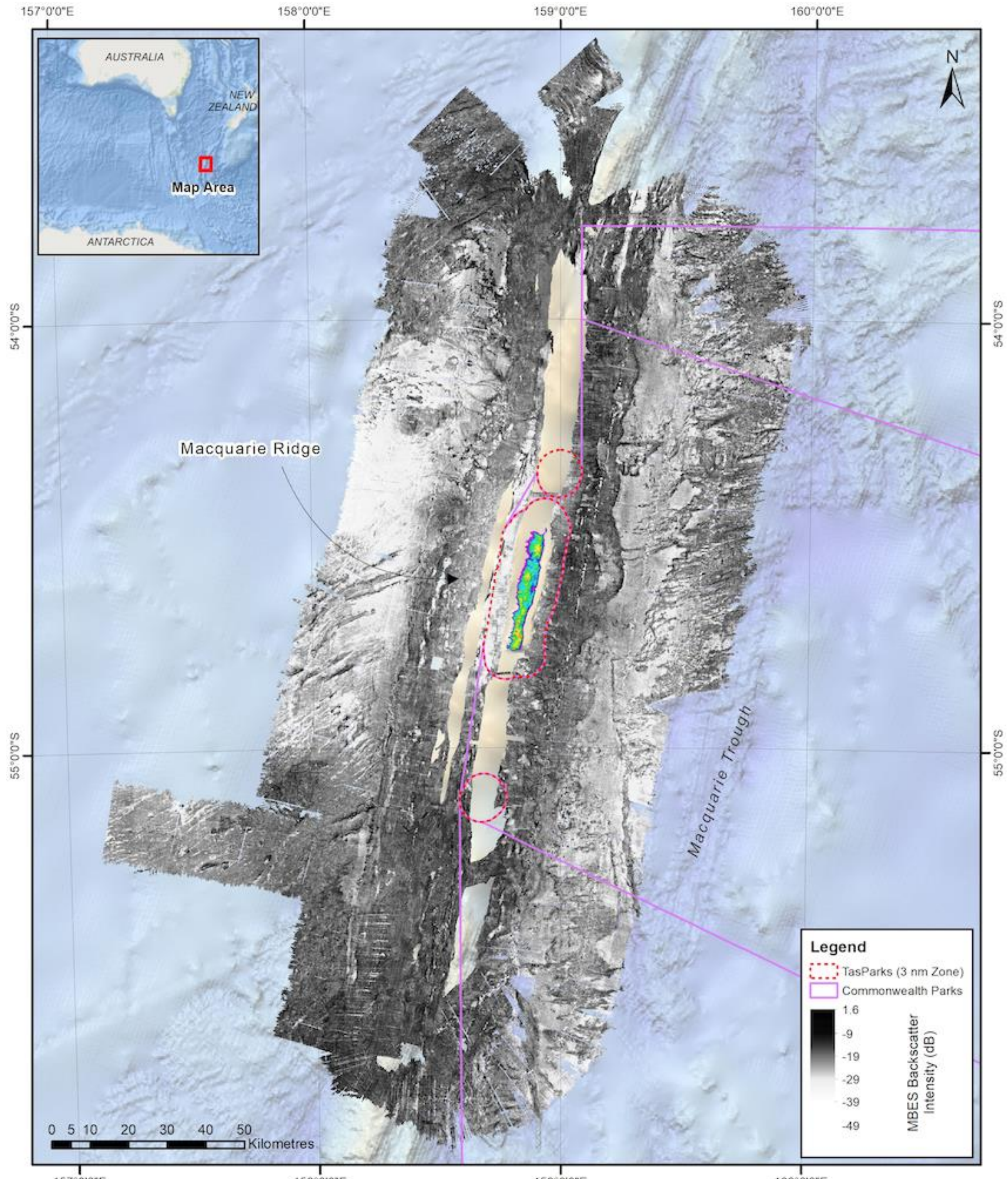


Figure 2. New IN2020_V06 multibeam backscatter map. Tasmanian Macquarie Island Nature Reserve – Marine Area and Commonwealth Macquarie Island Marine Park outlined, respectively, in dashed red and solid pink lines. Tan along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

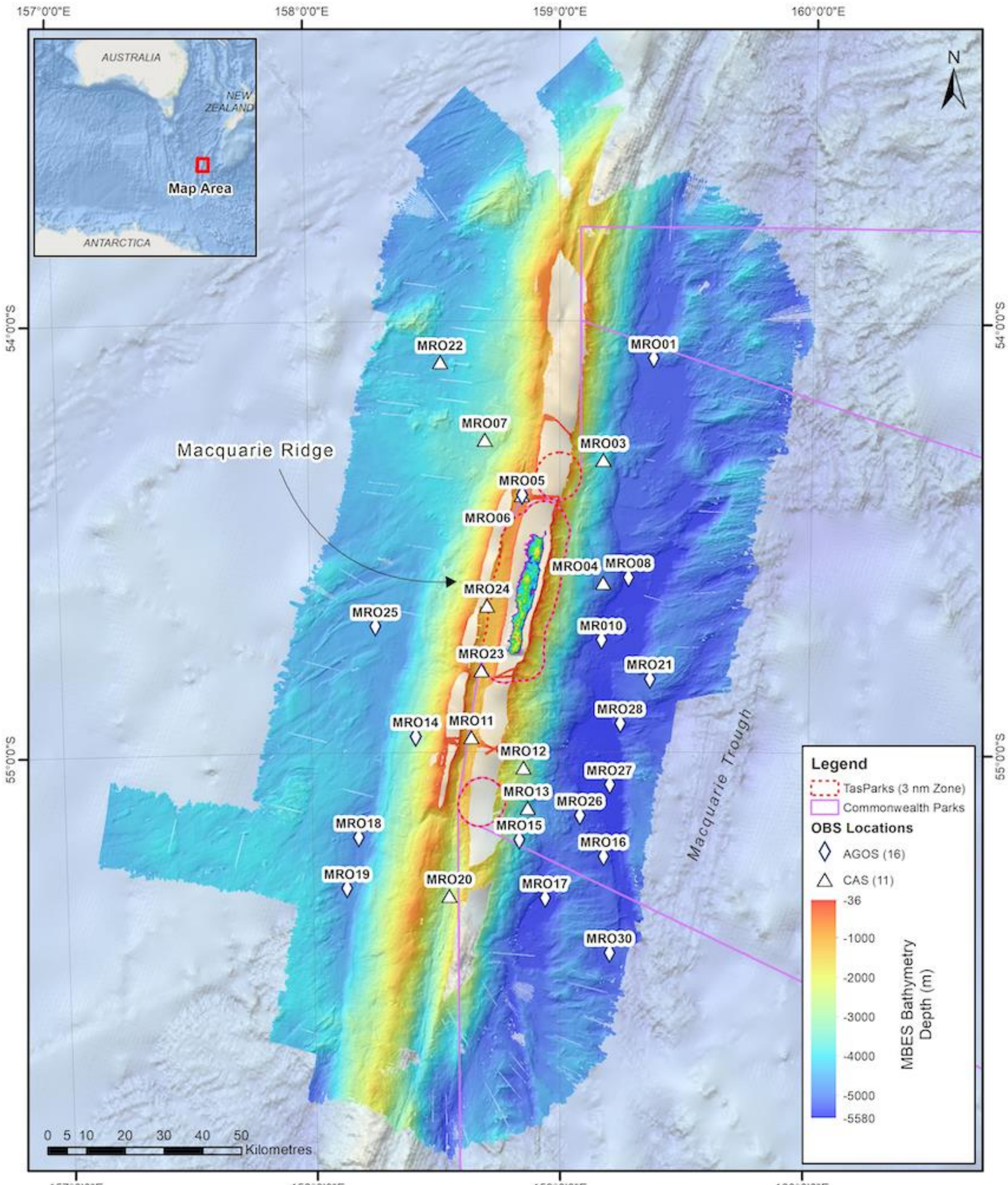


Figure 3. New IN2020_V06 multibeam bathymetry map with OBS deployment locations. Tasmanian Macquarie Island Nature Reserve – Marine Area and Commonwealth Macquarie Island Marine Park outlined, respectively, in dashed red and solid pink lines. Tan along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

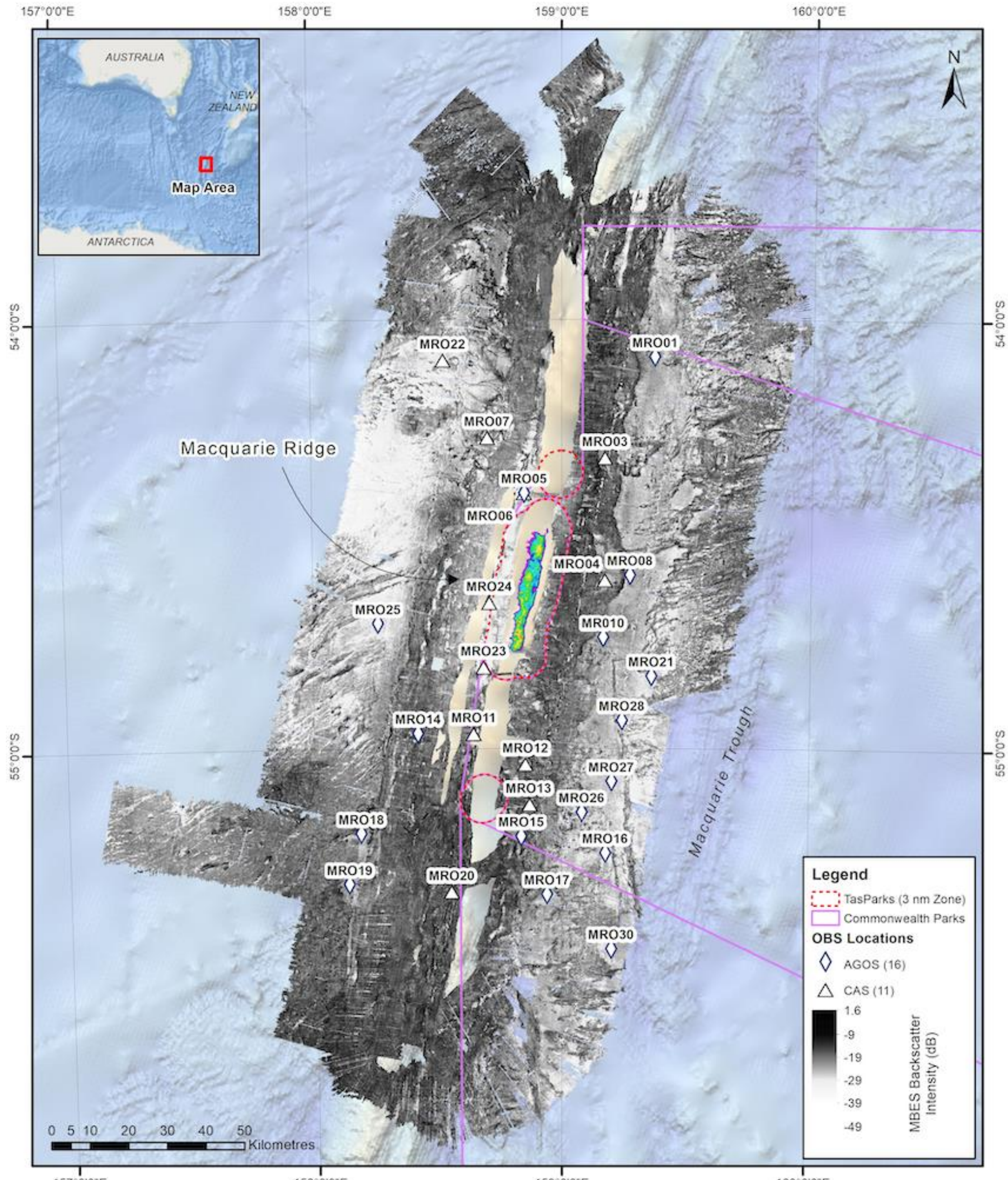


Figure 4. New IN2020_V06 multibeam backscatter map with OBS deployment locations. Tasmanian Macquarie Island Nature Reserve – Marine Area and Commonwealth Macquarie Island Marine Park outlined, respectively, in dashed red and solid pink lines. Tan along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

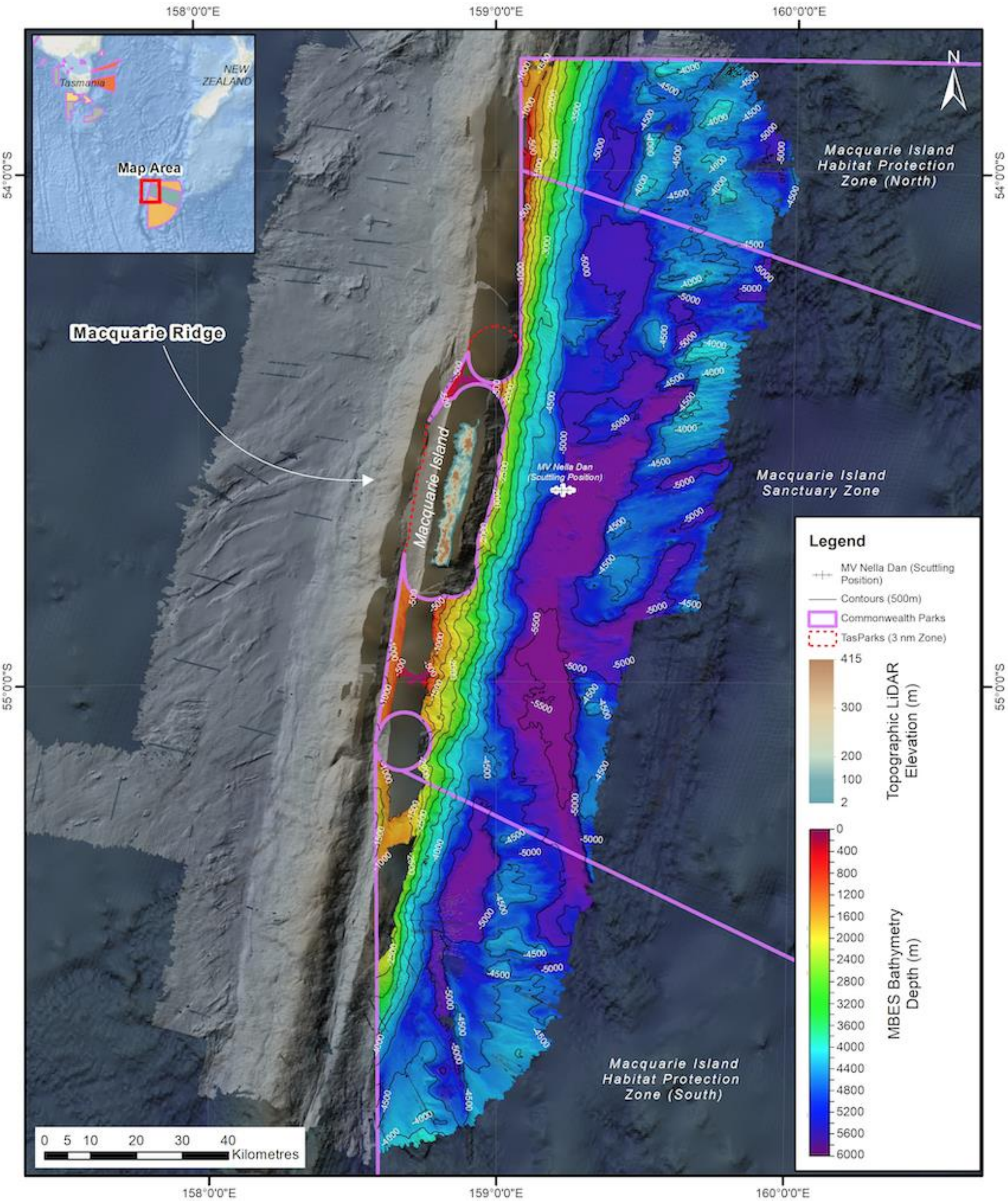


Figure 5. New IN2020_V06 multibeam bathymetry within the Commonwealth Macquarie Island Marine Park. Tasmanian marine reserve and Commonwealth Macquarie Island Marine Park outlined, respectively, in dashed red and solid pink lines. Dark gray along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

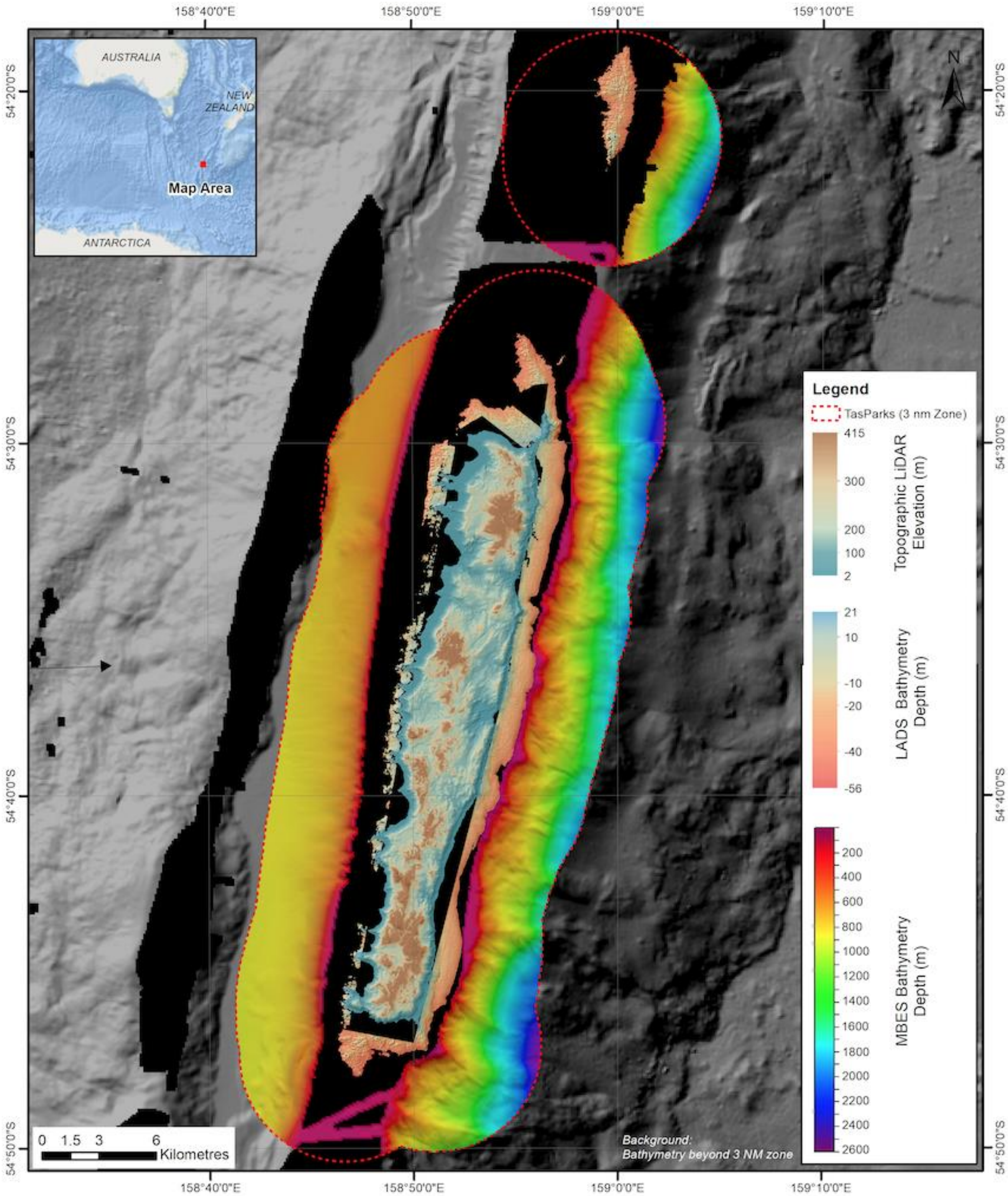


Figure 6. New IN2020_V06 multibeam bathymetry within the Tasmanian Macquarie Island Nature Reserve – Marine Area, outlined in dashed red line. Black along central MRC indicates areas not mapped. Inset shows large map area outlined in red.

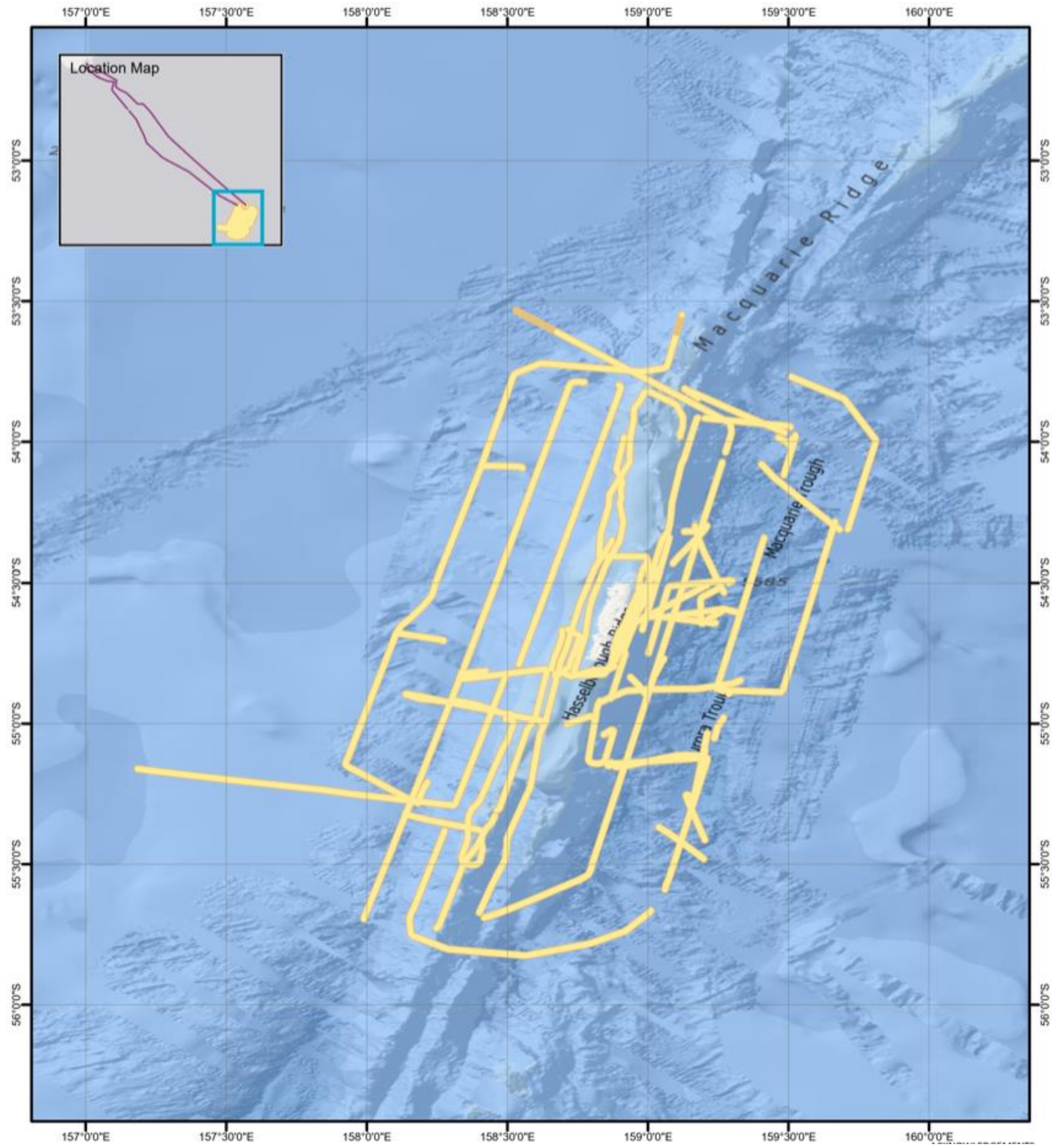


Figure 7. IN2020_V06 sub-bottom profiler (SBP120) track map. Inset shows large map area outlined in blue and transits in purple.

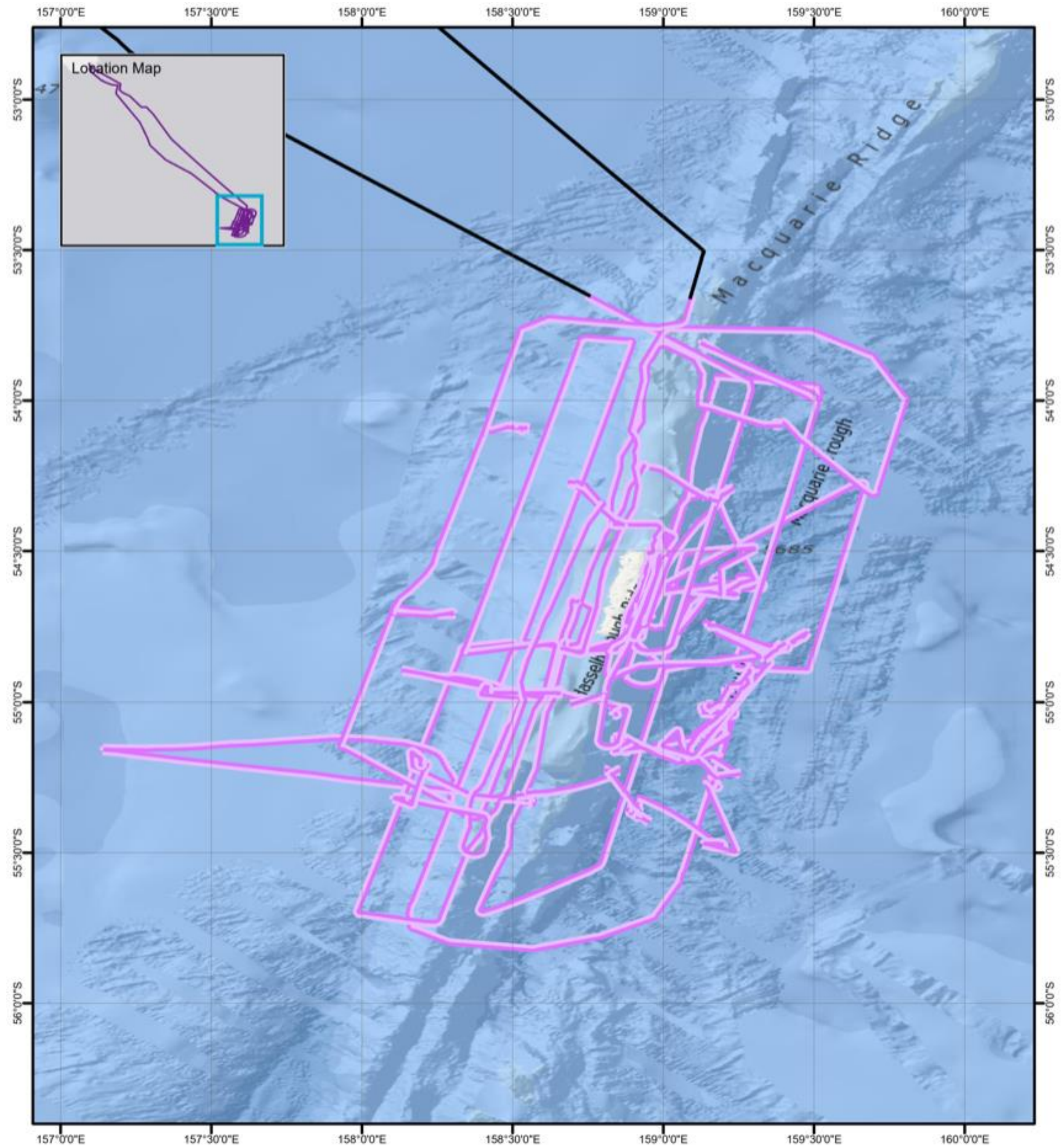


Figure 8. IN2020_V06 gravity track map. Inset shows large map area outlined in blue and transits in purple.

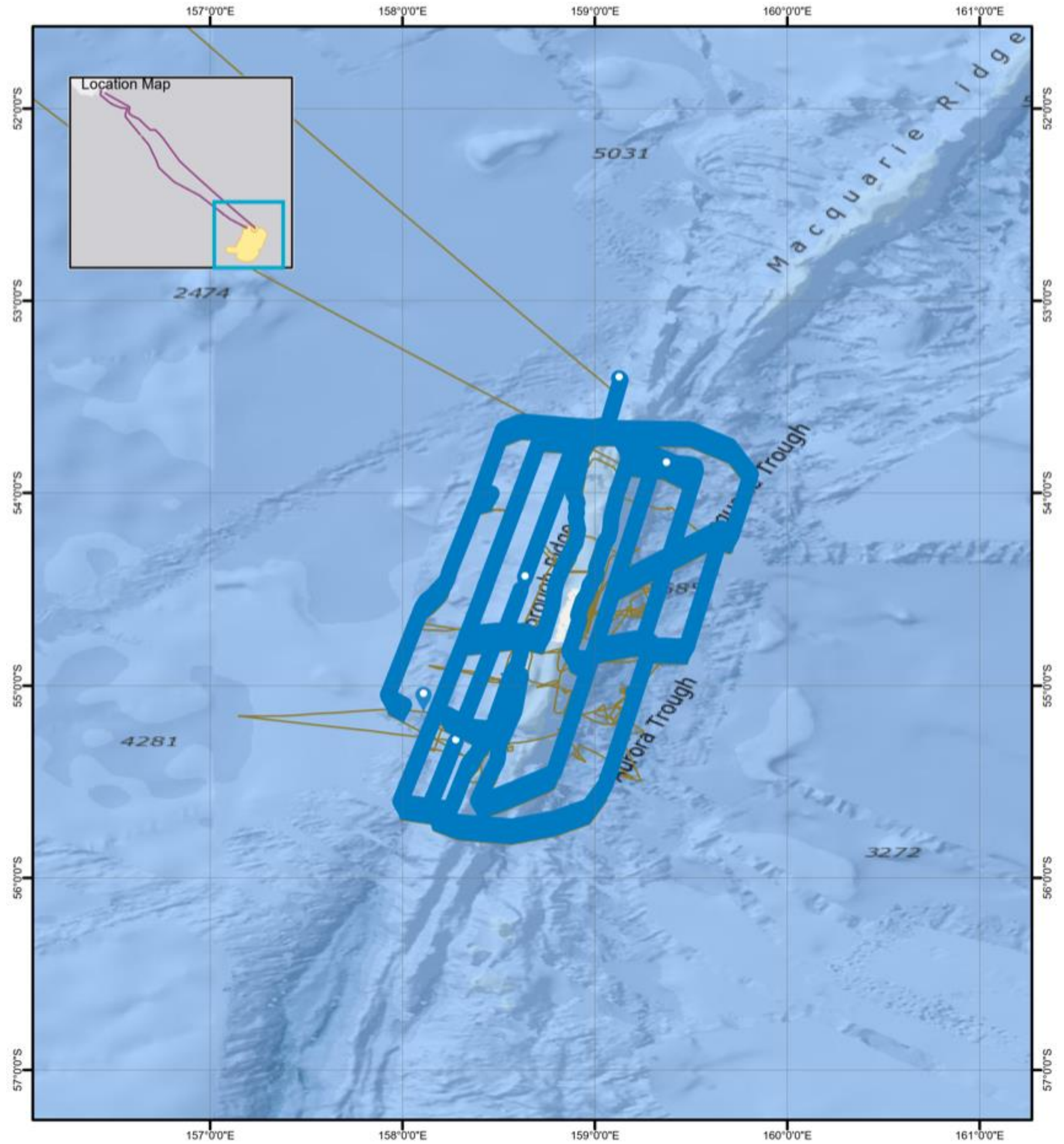


Figure 9. IN2020_V06 magnetics track map. Inset shows large map area outlined in blue and transits in purple.

Appendix D – Science Party Acknowledgement to ASP Crew

UNIVERSITY of TASMANIA | IMAS INSTITUTE FOR MARINE & ANTARCTIC STUDIES

3 November 2020

Master Michael Watson
Research Vessel *Investigator*

Dear Mike

The entire IN2020_V06 scientific party wishes to thank and commend you, Chief Officer Tom Watson, Chief Engineer Genna Gervasiev, CIR Jono Lumb, Chief Caterer Alan Martin & his team, and the rest of your able officers, engineers, and crew for your crucial contributions to the successful outcomes of IN2020_V06. The inaugural scientific deployment of Australia's entire pool of ocean bottom seismometers, complemented by hired instruments, constitutes a major achievement for the national and international marine geoscience community. Despite the numerous challenges presented by COVID-19 and an angry Neptune, you and your crew have been superbly cooperative, conscientious, capable, good-humoured, diligent, perceptive, thoughtful, and professional throughout the Furious Fifties. It has been an exceptional pleasure to work aboard this superlative vessel, especially with such competent, enthusiastic, and welcoming shipmates imbued with a positive, 'can-do' attitude.

We look forward to future opportunities to sail aboard *Investigator*.

Yours sincerely

Prof Millard 'Mike' F Coffin
University of Tasmania (UTAS)
Chief Scientist

Prof Hrvoje Tkalčić
Australian National University (ANU)
Alternate Chief Scientist

Dr Caroline Eakin
ANU
Principal Investigator

Dr Xiaolong Ma
ANU

Dr Thanh-Son Pham
ANU

Dr Robert Pickle
ANU

Thuany Patricia Costa de Lima
ANU

Rajesh Erigela
ANU

Andrew Latimore
ANU

Institute for Marine and Antarctic Studies
Hobart
Private Bag 129
Hobart TAS 7001
Australia

T +61 3 6226 2959
E mike.coffin@utas.edu.au
imas.utas.edu.au
ABN 30 764 374 782 / CRICOS 00586B

UNIVERSITY of TASMANIA | IMAS INSTITUTE FOR MARINE & ANTARCTIC STUDIES

Yun Fann Toh
UTAS

Sheng Wang
ANU

cc: Tim Wong, ASP
Toni Moate, CSIRO
Barbara Musso, MNF

Institute for Marine and Antarctic Studies
Hobart
Private Bag 129
Hobart TAS 7001
Australia
T +61 3 6226 2959
E mike.coffin@utas.edu.au
imas.utas.edu.au
ABN 30 764 374 782 / CRICOS 00586B