MNF Voyage Highlights and Summary

NOTE - The Chief Scientist should send the Voyage Highlights and Summary Report to the MNF Voyage Delivery Coordinator within 40 business days of the completion of the voyage. The Voyage Highlights and Summary needs to be submitted electronically as a Microsoft Word document so we can align formatting across all reports. **All guidance text in blue should be deleted**.

VOYAGE #:	**IN2024_V01**
Version Number:	FINAL
Voyage title:	Multidisciplinary Investigations of the Southern Ocean (MISO): Linking Physics, Biochemistry, Plankton, Aerosols, Clouds, And Climate
Mobilisation:	Thursday 28th- Sunday 31st December 2023, CSIRO Wharf PW04, Hobart
Pre-medical clearance period:	Monday 1st January – Thursday 4th January 2024, Hobart
Depart:	Friday 5th January 2024, (~0800) Selfs Point, Hobart
Return:	Tuesday 5th March 2024, Fremantle
Demobilisation:	Wednesday 6th March 2024, Fremantle
VDC and Voyage Manager:	Margot Hind
Chief Scientist:	Dr Steve Rintoul
Co-Chief Scientist & Sailing Chief Scientist	Dr Annie Foppert
Principal Investigators:	Alain Protat, Philip Boyd, Andrew Bowie, Elizabeth Shadwick, Annie Foppert, Robert Strzepek

Voyage Highlights

The Chief Scientist

Dr Annie Foppert is an early-career physical oceanographer at the University of Tasmania and the Australian Antarctic Program Partnership. Her research focuses on circulation and changes in the Southern Ocean, and the crucial role of the Southern Ocean in the climate system. Annie is a sea-going oceanographer who has participated in several oceanographic voyages in many parts of the world, including three in the Southern Ocean.


Dr Steve Rintoul is a physical oceanographer and climate scientist at CSIRO Oceans & Atmosphere, the Australian Antarctic Program Partnership, and the Australian Centre for Excellence in Antarctic Science. His research over the past 30 years has focused on the role of the Southern Ocean in the Earth's climate system. He has led 14 expeditions to the Southern Ocean. His research and scientific leadership have been recognised by national and international awards, including the Tinker-Muse Prize for Science and Policy in Antarctica, the George Wüst Prize (Germany), and the Australian Antarctic Medal. He is a Fellow of the Australian Academy of Science.

Title

Multidisciplinary Investigations of the Southern Ocean (MISO): Linking Physics, Biochemistry, Plankton, Aerosols, Clouds, And Climate

Purpose

The voyage took an integrated multidisciplinary approach to understand the Southern Ocean and atmosphere's role in the climate system. The overall objectives of the project are:

1. To collect integrated physical, biogeochemical, and biological observations of the coupled Southern Ocean – atmosphere system needed to address gaps in scientific understanding of key processes and to understand reasons for biases in Earth System Models (ESMs).
2. To use enhanced process-level understanding and observations to test and improve earth system models and for calibration/validation of satellite measurements.

Contribution to the nation

The Southern Ocean and overlying atmosphere have a profound influence on regional and global climate, sea level, biogeochemical cycles, and marine biological productivity. However, present-day models used for forecasts and projections have large and persistent biases in the region. MISO aims to enhance our understanding of how the Southern Ocean region influences the Earth system and use this knowledge to improve models.

MISO will characterise the properties of aerosols, clouds, radiation, and precipitation over the Southern Ocean south of Australia and investigate how they are shaped by interactions between the ocean, atmosphere and biosphere. Repeat observations will be used to discover how and why the region is changing, and the consequences of Southern Ocean change for climate, biogeochemical cycles, biological productivity, and the future of the Antarctic Ice Sheet. MISO data will provide new insights into the processes controlling the availability of iron and other trace elements and their role in regulating productivity in the Southern Ocean and the production of marine organic aerosols that can drive cloud nucleation.

The observations and insights gained from the voyage will be used to develop, test, and implement new parameterisations for models used for weather forecasts and climate projections. Better climate projections will underpin a more effective national response to the challenges of a changing climate.

As a result of this voyage

- We have collected the first comprehensive measurements of iron, and other trace elements essential for marine life, in this part of the ocean.
- We have made new observations that extend the longest record of deep ocean change south of Australia.
- We have made new observations that allow the tracking of how much carbon dioxide the Southern Ocean is removing from the atmosphere and storing in the deep ocean.
- We have deployed an array of novel deep floats, delivering snapshots of ocean conditions every ten days, from the sea surface to the sea floor.
- We have successfully conducted experiments analysing both the air and water within special onboard incubation tanks to measure how the composition and health of marine biota affect the emission of cloud-seeding gases.
- One of the planet's five regions with prominent stratocumulus clouds, the southeast Indian Ocean, has been sampled from the surface for the first time ever during MISO.
- The unique multidisciplinary data set collected on MISO will allow interactions between physical, biogeochemical, and biological processes - from the free atmosphere to the deep sea – to be understood and better represented in earth system models.

Next steps

There was a vast amount of multidisciplinary data collected during MISO. Some of the datasets will be finalised within a few months after the voyage (e.g. hydrochemistry and CTD data), while other datasets will take 6 months to a year to analyse (e.g. trace element and isotope data and biology data). Analysis of the datasets will commence as soon as possible and will be published in scientific journals, disseminated at international conferences, and used improve Earth System Models.

Voyage Summary

Executive summary

The Southern Ocean and overlying atmosphere have a profound influence on regional and global climate, sea level, biogeochemical cycles, and marine biological productivity. However, present-day models used for forecasts and projections have large and persistent biases in the region. MISO aims to enhance our understanding of how the Southern Ocean region influences the Earth system and use this knowledge to improve models.

Data collected during MISO will characterise the properties of aerosols, clouds, radiation, and precipitation over the Southern Ocean south of Australia and investigate how they are shaped by interactions between the ocean, atmosphere and biosphere. Repeat hydrographic observations will be used to discover how and why the region is changing, and the consequences of Southern Ocean change for climate, biogeochemical cycles, biological productivity, and the future of the Antarctic Ice Sheet. Data collected will provide new insights into the processes controlling the availability of iron and other trace elements and their role in regulating productivity in the Southern Ocean and the production of marine organic aerosols that can drive cloud nucleation.

The observations and insights gained from the voyage will be used to develop, test, and implement new parameterisations for models used for weather forecasts and climate projections. Better climate projections will underpin a more effective national response to the challenges of a changing climate.

Scientific objectives

The **overall objectives** of the project are:

1. To collect integrated physical, biogeochemical, and biological observations of the coupled Southern Ocean – atmosphere system needed to address gaps in scientific understanding of key processes and to understand reasons for biases in Earth System Models (ESMs).
2. To use enhanced process-level understanding and observations to test and improve earth system models and for calibration/validation of satellite measurements.

The specific research questions to be addressed are:

1. What processes and interactions account for the unique aerosol-cloud-precipitation-radiation interactions over the Southern Ocean and how can they be better represented in ESMs to reduce the large and persistent biases in clouds and absorbed solar radiation at the ocean surface?
2. How do biogenic ocean sources influence the aerosol, cloud, precipitation, and radiative properties of the Southern Ocean atmosphere and how can they be better parameterised in models?
3. How and why is the Southern Ocean inventory of heat and carbon south of Australia evolving in time and what are the impacts on sea level rise and ocean acidification?
4. What physical and biogeochemical processes control primary productivity, community composition, and production of biogenic aerosols?

5. How is the Southern Ocean changing near Antarctica and what are the implications for the stability of the Antarctic Ice Sheet and the formation of Antarctic Bottom Water?
6. How well are cloud, aerosol and precipitation properties over the Southern Ocean represented in satellite products and how can they be used to inform data assimilation?

Voyage objectives

Atmosphere: We will use shipboard and satellite instruments to investigate the latitudinal variability of cloud, aerosol, and radiative properties.

Air-sea interface: Ocean-atmosphere interactions will be measured with underway instruments. Air-sea fluxes of CO_2 and sea spray will be measured continuously along the ship track.

Ocean physics: We will re-occupy the I9S repeat hydrographic section at 115°E to assess changes in ocean properties and circulation. We will also track the ongoing and rapid change in Antarctic Bottom Water (AABW) by completing short sections across the AABW export pathway at 132°E, 140°E and 150°E. Deep Argo floats and Biogeochemical Argo floats will be deployed.

Ocean biogeochemistry: Carbon chemistry will be measured throughout the water column. Iron and other trace elements and isotopes (TEIs) will be measured using clean techniques. We will occupy 4 stations for ~3 days to track the evolution of iron biogeochemistry, measuring fluxes of particulate and dissolved iron pools, to investigate processes controlling strong opposing fluxes of iron regeneration and scavenging, organic ligand release, authigenic iron production, and biological uptake and recycling in the upper and mesopelagic ocean.

Ocean biology: Underway measurements will be used to map zonal and meridional distributions of phytoplankton stocks, community structure, physiological status, and biogenic gas concentrations (e.g. DMS). Process studies will focus on the marginal ice zone where phytoplankton blooms are anticipated to supply biogenic precursors to aerosol, cloud condensation nuclei (CCN), and Ice Nucleating Particles (INPs). During process stations, incubation experiments will be conducted on board to quantify the biological production of organic compounds and how they act as precursors for new formation of aerosols.

Satellite calibration/validation: Opportunistic observations collected during satellite overpasses will be used to evaluate and refine satellite aerosol, cloud, and precipitation products from the Himawari-8, A-Train,GPM and PACE missions.

Results

The data collected during the MISO voyage represent the most comprehensive dataset ever collected in this region. All of the above objectives were met.

Voyage narrative

The voyage was a great success. We were able to achieve all the voyage goals – with only 7 planned stations that were not occupied, and 6 of those 7 not occupied because they were inaccessible due to sea-ice cover. We were able to add additional opportunistic stations in the Adelie Depression near the Mertz Glacier region on the Antarctic shelf and in the Leeuwin Undercurrent-Current System off the southwest corner of Western Australia. All 22 float deployments were successful. The final station plan that was completed can be found in the Track Chart (Figures 1 and 2). Radiosondes were deployed regularly; the DALEC was deployed when weather permitted for PACE satellite validation.

Pre-voyage medical clearance days:

All personnel were pleased with the opportunities to do the test dips (CTD, TMR and ISPs) without any time pressure sometimes associated with “official” voyage activities (i.e. once sea-time starts ticking). Risks were identified, procedures were ironed out, erroneous calibration numbers were found, sampling techniques were practiced, etc. It was a great use of this time.

Transit south:

Favourable weather for most of the transit south allowed for an early arrival at our first southern waypoint, nearly one day ahead of schedule. In addition to regular radiosonde and XBT deployments, we took advantage of the transit south for three other activities, all of which highlight the opportunities for cross-voyage and/or cross-project collaboration.

1. We towed the Continuous Plankton Recorder from Tasmania to the SOTS mooring site, adding to the long-term plankton records in the Southern Ocean.
2. We deployed a full-depth CTD and shallow TMR (1500 m) at the SOTS mooring site, which will help to underpin and constrain seasonal variability observed in the long-term mooring timeseries.
3. We mapped the seafloor in a region important for Antarctic Circumpolar Current dynamics, where the strong currents interact with bathymetry to allow for transport of heat toward the Antarctic. This will complement and enhance the data collected from the previous voyage (IN2023_V07).

150°E (Leg 1):

Operations along 150E went smoothly, and the teams all found their grooves. Details on timing to between CTD recovery and TMR deployment were ironed out to maximise efficiency and minimize time on deck for the TMR.

Sea-ice coverage on the southern end of 150E made the southernmost station inaccessible, so the superstation on 140E was swapped with the process station on 150E and moved north to allow all superstation activities to be completed away from any sea ice.

2 Deep Arvor floats and 1 SOCCOM float were successfully deployed along this transect.

Adelie Depression / Mertz Glacier region:

Real-time monitoring of satellite ice imagery showed an opening to the Mertz Glacier region and Adelie Depression. An agreed alteration to the voyage plan allowed the ship to divert to the Mertz Glacier region and carry out three opportunistic CTD, TMR, and ISP deployments, and two bongo net tows in the Adelie Depression. We also increased the deployment frequency of XBTs and rapid-cast CTDs in the region. This is the first time the Dense Shelf Water formed in the Mertz Polynya has been sampled since 2017. These data are extremely valuable and will be very useful for interpreting the changes in Antarctic Bottom Water observed in the deep ocean, understanding trace metal input from glacial melt, and informing how continental airflow from Antarctica influences the atmospheric properties above the Southern Ocean – all key scientific objectives of the MISO voyage. All three Mertz stations were superstations, i.e. all included ISPs and the first two included bongos.

The lead we entered through had closed while we were inside the Mertz region occupying stations. We cruised along the ice edge looking for an opening but could not find one. Satellite ice imagery showed that the potential southern route along the Antarctic coast also appeared to be a dead end. As L'Astrolabe had only just left Dumont d'Urville station earlier that morning, we called for their assistance in escorting us out through the ice. This was (1) to ensure a safe exit and (2) to continue the planned science program as soon as possible.

140°E (Leg 2):

Successful repeat of the southern section of SR3. Lost ~1.5 days due to weather on this line.

Process Station #1 was not completed in full, as the second Triaxus tow and shallow TMR were cut from the plan due to bad weather. The deckboard incubation experiments were successful, however, the mesocosms were unfortunately unsuccessful. The tanks had acid remaining in them, as seen by very low pH of seawater and very high CO2 in the headspace of the tanks. The tanks were emptied before the weather arrived.

One Deep Arvor, one Deep SOLO, and one SOCCOM float were deployed successfully on this transect.

132°E (Leg 3):

Successful repeat of stations along 132E, previously occupied in 2018. Note that the northernmost station on 132E was dropped to gain back some contingency time used due to bad weather and at the additional sites in the Mertz Glacier region.

Process Station #2 occurred just south of a 'blob' of very high chlorophyll seen in the satellite data. The Triaxus was towed from the 'blob' station to the process station to resolve the gradient between inside and outside, or on the edge of, the bloom. After the mesocosm tanks were filled, weather again deteriorated, and operations ceased for about 19 hours. Some process station activities – bongos and the second Triaxus tow – were not fulfilled due to the weather deteriorating again towards end of station activities, but the process station was considered a success overall.

One Deep Arvor float, two Deep SOLO floats, and one SOCCOM float were all successfully deployed along this transect.

123°E (Leg 4):

Two CTD-only stations on 123E and associated Deep SOLO float deployments were successful.

115°E (I9S):

The southernmost five stations on I9S were inaccessible due to sea-ice cover. A station was added nearly due east of station 33 when we were unsure whether we would be able to access 33, which we eventually did. While operations were also delayed along I9S due to both weather and mechanical issues with the ship, we were able to keep on or ahead of schedule, given the contingency days in place, and the line was successfully completed.

A low-pressure system delayed operations at one of the superstations (station 51), causing an overall loss of about 2 days and limiting the amount of superstation activities we could complete. In the end, we were able to complete the full-depth CTD, full-depth TMR – which was prioritized over the shallow TMR in a weather window, with bottle depths chosen with the expectation that we may not be able to do the shallow TMR – and ISPs. Thus, we fulfilled nearly all the superstation activities.

Mechanical issues with the ship were encountered on southern part of I9S, causing a delay in operations due to slow transit times. While transit times between stations were extended, the ship's officers and crew were comfortable with operations continuing. The issue was quickly resolved by the ship's crew (~48 hours after major fault was identified).

We undertook two process stations and seven superstations on I9S. The first process station (PS3) did not include filling the mesocosm tank, to let the experiment from the prior process station continue to play out. There were issues with the first Triaxus tow at PS3 – including the Triaxus flying in such a way that there was a significant increase of tension on the wire – that resulted in the tow being aborted and the Triaxus requiring retermination. All activities were successfully completed at the final process station (PS4).

3 Deep SOLO and 7 SOCCOM floats were all successfully deployed.

Transit to Fremantle:

With ~36 hours of remaining time in the science budget, we undertook an opportunistic survey of Leeuwin Undercurrent-Current System, where we completed three SADCP and rapid-cast CTD transects across the shelf break. Over 6 hours was lost due to having to repeat the first transect because the SADCP was turned off and not recording currents. Full-depth CTDs were deployed on the offshore end of all three transects, as was a full-depth TMR at Leeuwin1 and Leeuwin3. Reduced resolution of hydrochemistry samples were collected (12 depths) and no carbon samples or biology samples were collected during this short survey.

We arrived off Fremantle in time to meet the pilot on the morning of 5 March 2024.

Outreach, education and communications activities

The voyage generated a lot of media attention, including live TV and radio interviews. The science team will continue to engage with the public via talks and media activities as results become finalised.

Summary

The MISO voyage plan was very ambitious, and we were able to accomplish the vast majority of planned activities – and in some cases even add activities. All voyage objectives were achieved. We arrived in Fremantle to conclude the 65-day voyage having successfully completed many activities, including (but not limited to):

- 103 CTD casts
- 72 TMR casts
- 16 ISP deployments
- 14 bongo net tows
- 5 Triaxus tows
- 22 profiling float deployments (12 Deep Argo and 10 SOCCOM BGC-Argo)
- 4 surface drifter deployments
- 109 XBT deployments
- 27 rapid-cast CTD deployments
- 160 radiosonde deployments
- 2 mesocosm incubation experiments
- 26 deckboard incubation experiments
- 1 continuous plankton recorder (CPR) tow

We gratefully acknowledge the support and hard work of the crew and the MNF support staff on board, and all those who supported these efforts from shore. We would also like to acknowledge the Australian Antarctic Program Partnership (AAPP) for its support for this voyage.

Curation Report

Delete section if not applicable. Describe the storage location for all data/samples collected during the voyage, with each data/sample type included on a separate row. Details should include where the data/samples are being archived/curated, who is responsible for their curation, how the data/samples will be made accessible and to whom, and any further analyses that are underway/will commence.

Item #	Description	Storage	Access	Custodian
	Dissolved Inorganic Carbon		Raw Data – NCMI Information and Data Centre Final Data - Global Ocean Data Analysis Project (GLODAP)	Elizabeth Shadwick
	Total Alkalinity		Raw Data – NCMI Information and Data Centre Final Data - Global Ocean Data Analysis Project (GLODAP)	Elizabeth Shadwick
				Please continue on a separate sheet if necessary

Track Chart

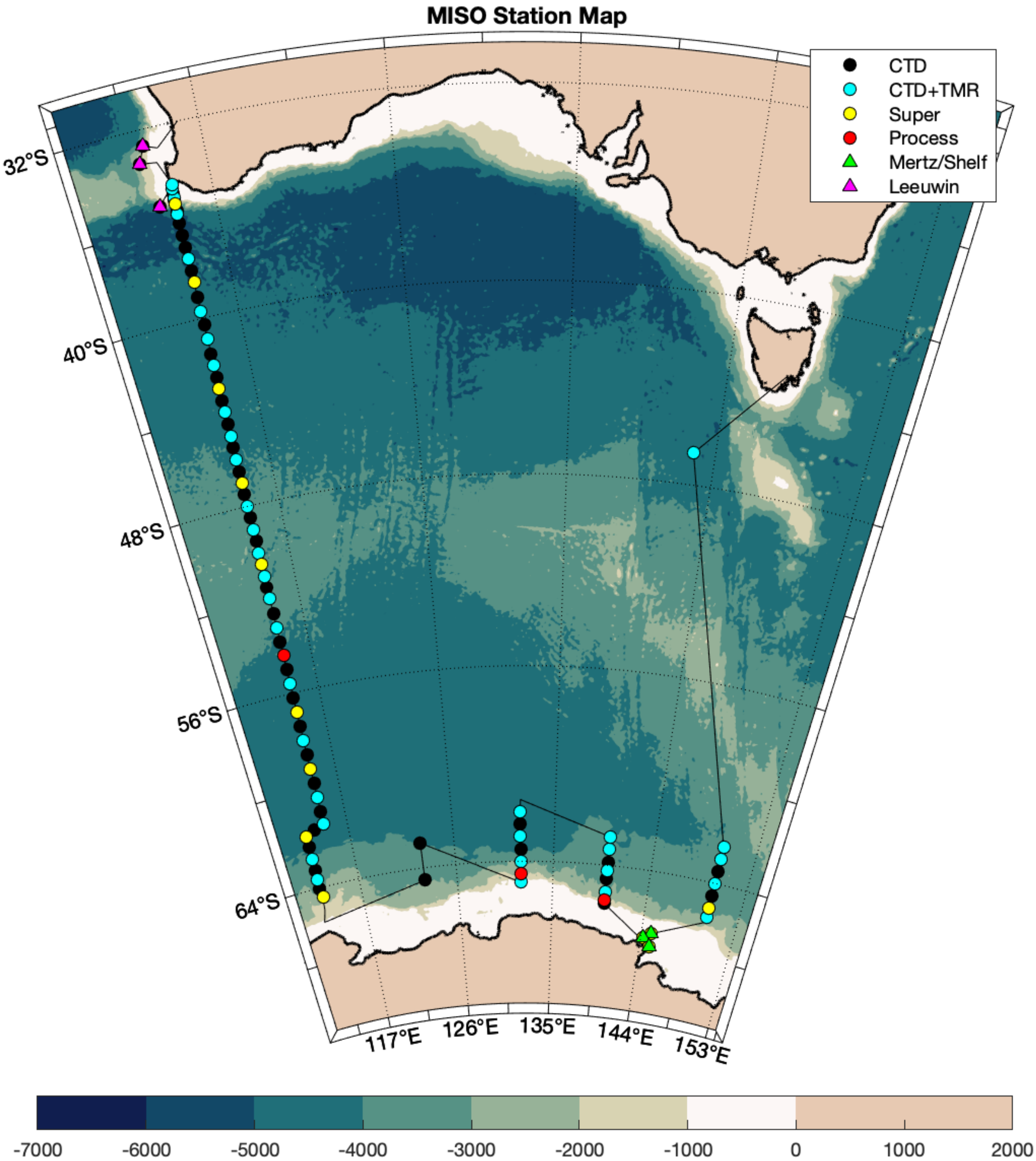


Figure 1. Map of MISO (IN2024_V01) station occupations. Note that the black line is only a graphical representation of the actual ship track.

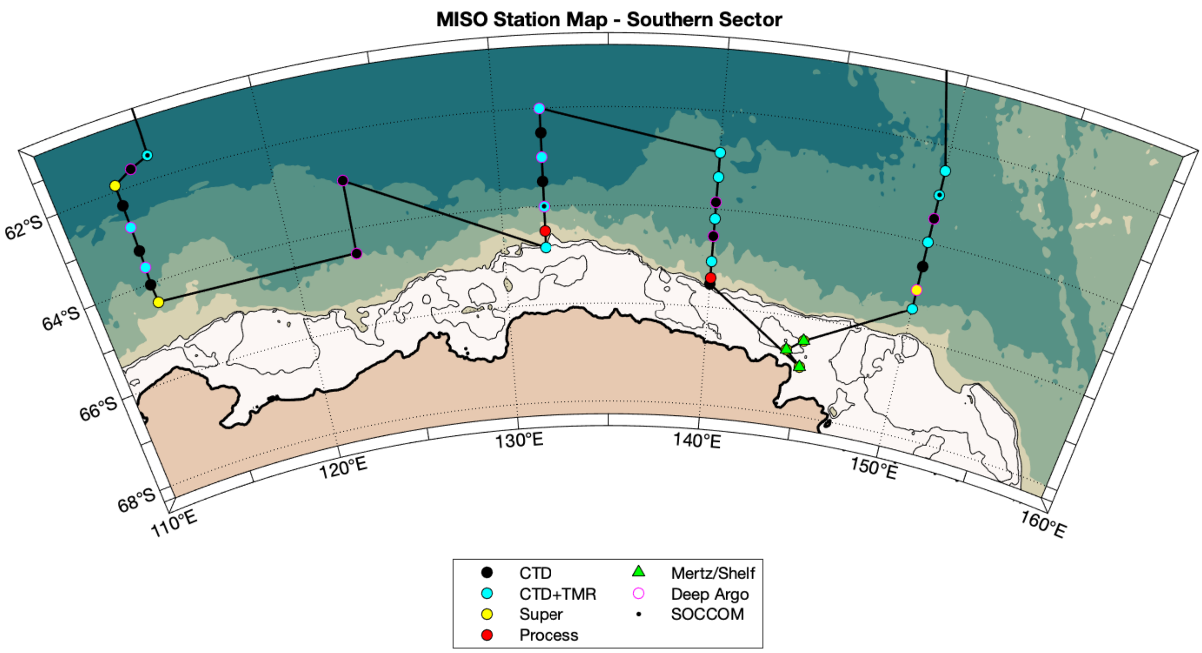


Figure 2. Map of the southern sector of the station plan, showing float deployment locations.

Links to Further Data and Information

NCMI Information and Data Centre (csiro.au)

Data Trawler (csiro.au) – Data Extraction tools for Voyage Data

MNF Reporting (csiro.au) – Publications and reports from research on vessels run by the Marine National Facilty

Marlin3 - Marlin - CSIRO Oceans and Atmosphere Metadata Catalogue

Open Access to Ocean Data (aodn.org.au)

AusSeabed (ausseabed.gov.au)

CAAB - Codes for Australian Aquatic Biota (csiro.au)

Ocean Biodiversity Information System - Australia (obis.org.au)

Atlas of Living Australia (ala.org.au)

CSIRO Data Access Portal (data.csiro.au)

Global Biodiversity Information Facility (GBIF) (gbif.org)

Insert below any links to further information and data from your voyage.

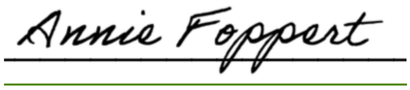
Description	**Link**

Description	Link

Acknowledgements

Please insert acknowledgements to organisations, teams or individuals that have supported your project(s).

Signature

Your name:	Annie Foppert
Title:	Chief Scientist
Signature:	
Date:	22 April 2024