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## RV *Investigator* Underway Data Processing Report

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|------------------------|---|
| <b>Voyage ID</b>       | <b>IN2024_V01</b>   |
| <b>Voyage Title</b>    | Multidisciplinary Investigations of the Southern Ocean (MISO) |
| <b>Depart</b>          | Hobart TAS, Monday 1 <sup>st</sup> January 2024 21:00 UTC     |
| <b>Return</b>          | Freemantle WA, Monday 4 <sup>th</sup> March 2024 02:20 UTC    |
| <b>Chief Scientist</b> | Dr Steve Rintoul (CSIRO)                                      |
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# Document History

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| 11 April 2024 | 1.0            | Vito Dirita   | Draft Version   |
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# 1 Summary

The goal of Multidisciplinary Investigation of the Southern Ocean (MISO) was to improve our understanding of how the Southern Ocean region influences the Earth system and use this knowledge to improve models. The voyage investigated how interactions between the atmosphere, ocean, and biosphere control processes as diverse as cloud formation, iron supply to marine life, ocean carbon uptake, and the drivers of rapid change in the deep ocean.

This report describes the production of quality controlled underway data from RV *Investigator* voyage IN2024\_V01.

To access the full voyage plan and other reports and data associated with this voyage, please see the contact information at the end of this report.

## 1.1 Voyage Track

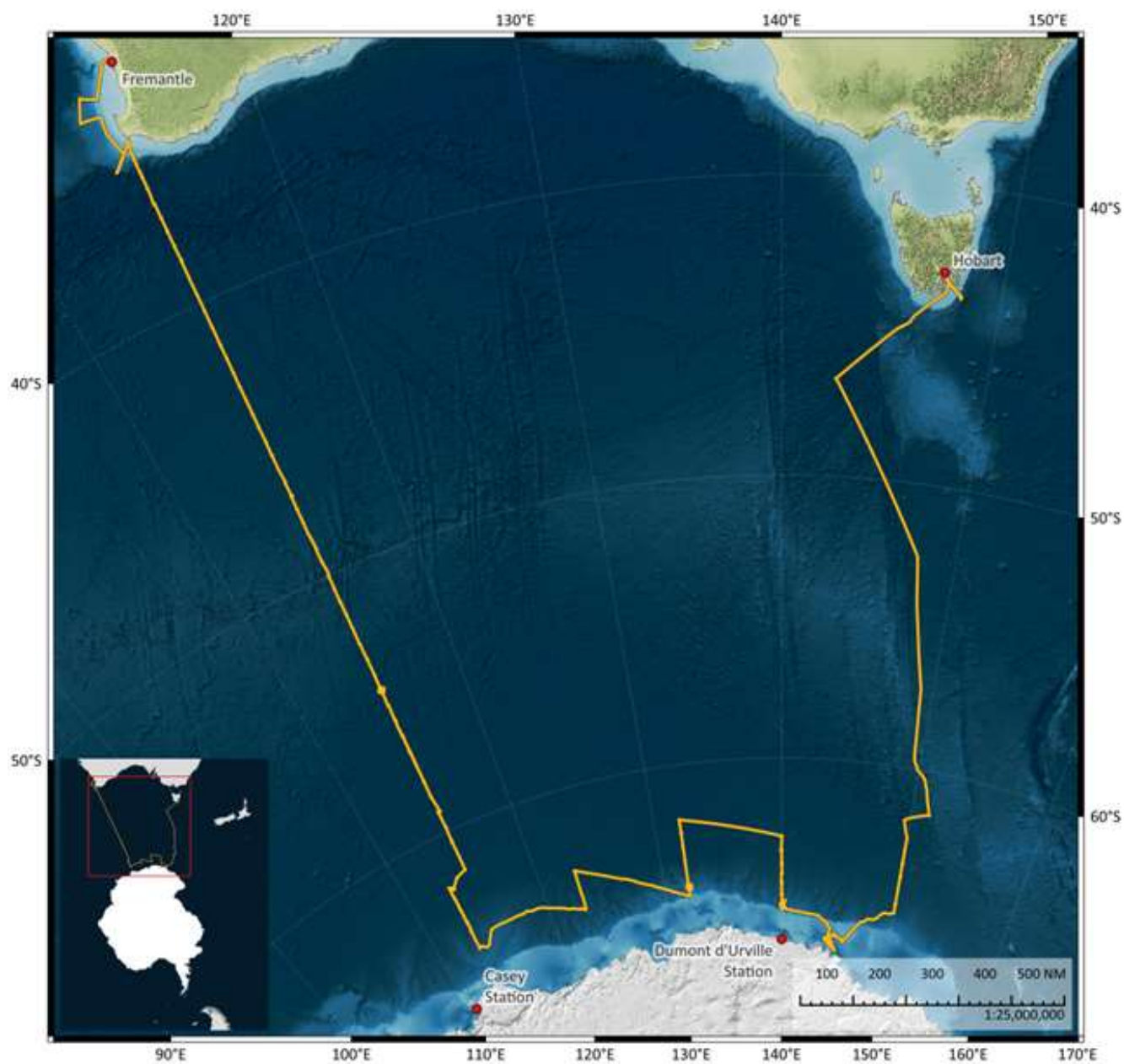


Figure 1: Voyage track

## 2 Data Processing

### 2.1 Background Information

Navigation data are acquired using the Kongsberg Seapath 330+ position and reference unit those data are differentially corrected by data from the Fugro Seastar 3610 DGNS Receiver.

The meteorological data consist of two port/starboard relative humidity and temperature sensors, vane-type wind sensors, LI-COR photosynthetically active radiation (PAR, light) sensors and a barometric air pressure sensor.

Data from the Integrated Marine Observing System (IMOS) sensors are also included. The sensors are port and starboard radiometers and pyranometers, and ultrasonic wind speed and direction.

Refer to the Seagoing Instrumentation Report for this voyage for details of the instruments used and their serial numbers.

Navigation, meteorological, IMOS and Thermosalinograph (TSG) data are preliminarily quality controlled by combining all data from hourly recorded files into 5-second-averaged values in a NetCDF formatted file. The combined data are referred to as “*underway data*”.

A combined underway data file was made on the 14<sup>th</sup> March 2024 (UTC) by running the Java application UWYMerger (version 1.8.1) with a data time range of 02-Jan-2024 00:34:35 to 05-Mar-2024 02:28:05 (UTC).

Further, it should be noted that the merged data file contains additional underway sensor data that are not quality controlled or processed and are provided for completeness only. This includes data from the air sampling instruments (i.e., two ozone sensors, an absorption photometer, Picarro sensors and a sampling inlet bearing), a pCO<sub>2</sub> sensor, the drop keel position, the water depth and the gyroscopic compass.

For further descriptions of the instruments, their respective locations on the vessel and Underway NetCDF variables please refer to the Appendices at the end of this report.

## 2.2 Completeness and Data Quality

Navigation data (latitude and longitude, speed over ground, ship heading and course over ground), meteorological data (port and starboard for each of air temperature, relative humidity, relative and true wind speed and direction, PAR, rain, and atmospheric pressure), IMOS data (port and starboard radiometers and pyranometers, ultrasonic relative wind direction and speed) and Thermosalinograph data (salinity and water temperature) were evaluated and quality controlled (QC'd). It should be noted that the underway NetCDF file contains the raw unQC'd data. Therefore, even though the QC'd variable may have been set to NaN or otherwise adjusted or filtered out, the raw data variable is always available in the NetCDF underway file. This is useful if the end-user wishes to apply a different QC or filtering methodology.

## 2.3 Processing Comments

### 2.3.1 Atmospheric Pressure

No issues were found with the barometric sensor. The foremast digital barometer was used.

### **2.3.2 Air Temperature**

Some minor discrepancies between the port and starboard air temperature sensors were noted (mean absolute difference of 0.078C°), otherwise both sensors gave very close readings. These discrepancies usually occur during periods of rapid temperature change. This phenomenon has probably come about due to the rapid warming of the ship's metal structure and air due to the ship becoming stationary or cooling of the air temperature due to the ship speeding off from stationary or the evaporation of rainwater around the sensor housing. Furthermore, they also seem to relate to when the ship is stationary with little wind or during/following periods of rainfall or as the result of a change in the ship speed that could be the result of hot exhaust gases being blown over the sensors depending on the wind direction.

### **2.3.3 Latitude/Longitude**

No major issues were found with latitude and longitude data with only a few minor points flagged BAD and set to NaN.

### **2.3.4 Humidity**

No issues were found with the humidity data, both sensor readings reached 100% saturation on several occasions throughout the voyage however.

### **2.3.5 Rain**

No issues found with the rain sensors. Please note that differences less than the specified  $\pm 1$  mm accuracy of the instrument are generally ignored.

### **2.3.6 Wind Speed & Direction**

Minor discrepancies between the port and starboard vane wind speed and direction readings were noted, otherwise both sensors gave very close readings. It has been observed that due to the location of the port wind sensor relative to the ship's superstructure, the instrument could experience some interference when the wind direction is approximately from the starboard stern (appx. 130 degrees). This results in greater fluctuations in both speed and direction measurements. Likewise, the starboard wind speed and direction sensor experiences similar interference when the wind direction is approximately from the portside stern (appx. 240 degrees). Under these conditions, if the wind direction is either near 130 or 240 degrees and the wind speed measurement has abruptly dropped by more than 14 knots due to obstruction by the superstructure, then the corresponding sensor data is flagged as bad and set to NaN for either port or starboard respectively. Furthermore, the value of 14 knots is estimated from the mean difference in wind speed between the port and starboard sensors when the wind direction is either approximately 120-140 degrees or 230-250 degrees plus 1 standard deviation.

### **2.3.7 Course Over Ground (courseOG) & Speed Over Ground (speedOG)**

Ship position and speed (speedOG) are measured by differential GNSS using phase-smoothed pseudo-range and Doppler observations. When using high precision differential correction, a worldwide accuracy of 10-20 cm is possible. Course over ground describes the direction of motion with respect to the ground that a vessel has moved relative to the geographic north pole. Accordingly, should a vessel be stationary, it is not travelling a course (e.g., at the wharf). Under conditions where a vessel is experiencing leeway (wind, current), a vessel's heading and courseOG may differ. This difference will typically be the largest for vessels moving at slow speeds. When the ship speed is less than 0.5 knots (25.7 cm/s), courseOG values fluctuate and are highly variable. Course and speed over the ground were recomputed from 5-second latitude and longitude values (truncated to 6 decimal places, 0.000001 degree latitude = 11.112 cm). No issues were found with the ship's course over ground readings. The resulting course over ground values were compared to the original GPS-derived values and agreed well. When the values agree well, a slight smoothing is achieved when the ship is underway, and when the ship is almost stationary the result is similarly variable. No issues were found with the ship's speed over ground readings.

### **2.3.8 Ship Heading**

No major issues were found with the ship heading data with only a few minor points flagged BAD and set to NaN.

### **2.3.9 Photosynthetically Active Radiation (PAR)**

Minor discrepancies between the port and starboard PAR sensor readings were noted and flagged as SUSPECT, otherwise both sensors gave very close readings. The stbdPAR baseline appears to be at  $1 \mu E/m^2/s$  instead of zero, this is likely due to a rounding off from 0.7 to 1.0 caused by background or stray noise.

### **2.3.10 Pyranometer**

Minor discrepancies between the port and starboard Pyranometer sensor readings were noted and flagged as SUSPECT, otherwise both sensors gave very close readings. Please note that night-time observations can result in small negative offset readings ( $-4.4 W/m^2$ ), these readings are still acceptable and within the rated specifications of the instrument.

### **2.3.11 Radiometer**

No issues were found with the radiometer data.

### **2.3.12 Ultrasonic Wind Speed & Direction**

When the wind is roughly from the starboard stern of the ship (appx. 130 degrees) the ultrasonic wind direction values can exhibit wild variations (i.e., large spikes) which are not manifested by the two vane-type wind sensors to the same extent. It is believed that this characteristic is most likely caused by the interaction of the ship's superstructure, foremast, ship motion and the wind in

relation to the ultrasonic wind sensor. Furthermore, when the wind direction is from the starboard stern and the wind speed measurement has abruptly dropped by more than 14 knots due to the superstructure obstruction, then the corresponding sensor data is flagged as bad and set to NaN. Please note that the ultrasonic sensor is mounted in close proximity and below the port wind vane sensor resulting in closer agreement when compared with the starboard wind vane sensor. Additionally, the value of 14 knots is estimated from the mean difference in wind speed between the ultrasonic and starboard sensors when the wind direction is either approximately 120-140 degrees plus 1 standard deviation.

### **2.3.13 Water Temperature**

Approximately 5.3% of the water temperature data is missing, otherwise no major issues were found with the remaining data.

### **2.3.14 Salinity**

No major issues were found with the salinity sensor readings. Please note that when the TSG pump is switched off (i.e., `tsgFlow` is near zero) the salinity measurements start to randomly drift, these are subsequently set to NaN and the QC flag set to BAD.

### **2.3.15 Thermosalinograph (TSG) Calibration**

During the voyage, bottle salinity samples were collected from the underway seawater supply approximately every 3-5 days, and the precise time of each sample was recorded in EVERLog. A total of 60 bottle samples were collected and analysed. These values were compared with the underway salinity measured by the TSG at the exact same date/time and then used to calculate a conductivity scaling coefficient for the TSG using Multiple Linear Regression. This resulted in a scaling coefficient of 0.99977568. The residual had a standard deviation (SD) of 0.00015128 PSU (better than the required  $\leq 0.01$  PSU). This was then applied to the salinity data, a QC flag was set, and the data state for each data point was set to either 'good', 'suspect', 'no QC' or 'bad'. See [Table 3](#) in section 2.5 for further information on QC flags and data states. Salinity bottle calibration data can be found in the following downloadable file: **IN2024\_V01\_UWY\_TSGCal\_BottleResults.csv**.

### **2.3.16 TSG Lag**

Examination and comparison of the TSG water temperature profile against the sea surface water temperature showed a lag of approximately 2.8 minutes (170 seconds) between the two data sets and a mean thermal increase of  $+0.272^{\circ}\text{C}$  from the intake keel to the TSG. This lag is due to the time taken for the water to flow from the water intake on the port drop keel (where sea surface water temperature is measured by the SBE38 sensor) to the TSG located in the underway seawater lab on the ship (where the TSG sensor measures the temperature and conductivity of the water pumped in from the drop keel intake). When the precise location for the TSG salinity measurement is critical, this lag needs to be accounted for to determine the exact geolocation of the sampled water. For example, assuming the ship is moving at 10 knots and it takes 2.8 minutes (transport lag) for the water to flow from the drop keel intake to the TSG, the TSG salinity measurements would be for a

location about 875 meters away from the ship’s location at the time of the TSG’s measurements. The intake depths for the TSG and SBE38 SST intakes on the port drop keel are described in the Appendix. Note that the port drop keel extension was set to 1.2m for the duration of the voyage, the ship’s draft is nominally 6.0m, thus the TSG intake port is located 6.0m+1.2m (7.2m) below the water line.

### 2.3.17 Depth

The water depth data are no longer processed as part of the underway data set. The non-QC’d depth data are available in the raw underway data. The QC’d water depth data may be obtained from the processed GSM dataset (centre beam) for this voyage.

### 2.3.18 Other Data Sets

#### Raw Underway Data

It should be noted that the underway NetCDF file contains the raw unQC’d data. Therefore, even though the QC’d variable may have been set to NaN or otherwise adjusted or filtered out, the raw data are always available in the QC’d underway file. This is useful if the end-user wishes to apply a different QC or filtering methodology.

### 2.3.19 Comparing Port and Starboard Sensors

The following table below compares the mean-absolute-differences and max-absolute-differences between port and starboard sensor outputs before and after QC has been applied. Please note that the **After QC** columns only account for values that are flagged as ‘good’.

| Sensor                  | Before QC       |                | After QC        |                | Units           |
|-------------------------|-----------------|----------------|-----------------|----------------|-----------------|
|                         | mean(abs(diff)) | max(abs(diff)) | mean(abs(diff)) | max(abs(diff)) |                 |
| Air Temperature         | 0.08            | 0.9            | 0.08            | 0.9            | degrees Celsius |
| Humidity                | 0.43            | 12             | 0.43            | 12             | %RH             |
| Relative Wind Speed     | 1.68            | 32.22          | 1.65            | 28.69          | knots           |
| True Wind Speed         | 1.61            | 32.63          | 1.58            | 31.5           | knots           |
| Relative Wind Direction | 5.41            | 179.98         | 5.23            | 179.53         | degrees         |
| True Wind Direction     | 4.88            | 179.88         | 4.86            | 179.8          | degrees         |
| PAR                     | 37.17           | 1649           | 36.54           | 1649           | $\mu E/m^2/s$   |
| Pyranometer             | 10.42           | 798.2          | 10.42           | 798.2          | $W/m^2$         |
| Radiometer              | 1.95            | 25.3           | 1.95            | 25.3           | $W/m^2$         |
| Rain                    | 0.02            | 1.1            | 0.02            | 1.1            | mm              |

Table 1: Port and starboard sensor statistics before and after QC

## 2.4 Final Underway Data

The following table below provides a list of sensor names, the corresponding QC flag name and percentage GOOD, SUSPECT, BAD and MISSING data.

|    | Parameter Name          | parameterQC               | % Good | % Suspect | % Bad | % Missing |
|----|-------------------------|---------------------------|--------|-----------|-------|-----------|
| 1  | latitude                | latitudeQC                | 100    | 0         | 0     | 0         |
| 2  | longitude               | longitudeQC               | 100    | 0         | 0     | 0         |
| 3  | speedOG                 | speedOGQC                 | 99.99  | 0         | 0     | 0.01      |
| 4  | courseOG                | courseOGQC                | 99.99  | 0         | 0     | 0.01      |
| 5  | shipHeading             | shipHeadingQC             | 99.98  | 0         | 0.02  | 0         |
| 6  | portAirTemp             | portAirTempQC             | 100    | 0         | 0     | 0         |
| 7  | stbdAirTemp             | stbdAirTempQC             | 100    | 0         | 0     | 0         |
| 8  | portHumidity            | portHumidityQC            | 100    | 0         | 0     | 0         |
| 9  | stbdHumidity:           | stbdHumidityQC            | 100    | 0         | 0     | 0         |
| 10 | atmPressure:            | atmPressureQC             | 100    | 0         | 0     | 0         |
| 11 | portRelWindDir          | portRelWindDirQC          | 99.85  | 0.03      | 0.12  | 0         |
| 12 | stbdRelWindDir          | stbdRelWindDirQC          | 99.89  | 0.01      | 0.1   | 0         |
| 13 | portTrueWindDir         | portTrueWindDirQC         | 99.98  | 0         | 0.01  | 0.01      |
| 14 | stbdTrueWindDir         | stbdTrueWindDirQC         | 99.99  | 0         | 0.01  | 0         |
| 15 | portRelWindSpeed        | portRelWindSpeedQC        | 99.86  | 0.14      | 0     | 0         |
| 16 | stbdRelWindSpeed        | stbdRelWindSpeedQC        | 99.94  | 0.02      | 0.04  | 0         |
| 17 | portTrueWindSpeed       | portTrueWindSpeedQC       | 99.93  | 0.06      | 0     | 0.01      |
| 18 | stbdTrueWindSpeed       | stbdTrueWindSpeedQC       | 99.96  | 0         | 0.04  | 0         |
| 19 | maxWindGust             | maxWindGustQC             | 99.87  | 0.13      | 0     | 0         |
| 20 | portRain                | portRainQC                | 100    | 0         | 0     | 0         |
| 21 | stbdRain                | stbdRainQC                | 100    | 0         | 0     | 0         |
| 22 | portPAR                 | portPARQC                 | 99.89  | 0.11      | 0     | 0         |
| 23 | stbdPAR                 | stbdPARQC                 | 99.93  | 0.07      | 0     | 0         |
| 24 | portPyranometer         | portPyranometerQC         | 99.96  | 0.04      | 0     | 0         |
| 25 | stbdPyranometer         | stbdPyranometerQC         | 99.99  | 0.01      | 0     | 0         |
| 26 | portRadiometer          | portRadiometerQC          | 100    | 0         | 0     | 0         |
| 27 | stbdRadiometer          | stbdRadiometerQC          | 100    | 0         | 0     | 0         |
| 28 | ultrasonicRelWindSpeed  | ultrasonicRelWindSpeedQC  | 99.50  | 0         | 0.5   | 0         |
| 29 | ultrasonicTrueWindSpeed | ultrasonicTrueWindSpeedQC | 99.49  | 0         | 0.5   | 0.01      |
| 30 | ultrasonicRelWindDir    | ultrasonicRelWindDirQC    | 99.58  | 0.09      | 0.33  | 0         |
| 31 | ultrasonicTrueWindDir   | ultrasonicTrueWindDirQC   | 99.87  | 0.01      | 0.11  | 0.01      |
| 32 | salinity                | salinityQC                | 97.04  | 0         | 0.32  | 2.64      |
| 33 | waterTemp               | waterTempQC               | 94.45  | 0         | 0.23  | 5.32      |

Table 2: Final underway (CSV) QC'd data

## 2.5 Commonly Used QC Flags

The underway datasets include quality control (QC) flags which are described in more detail in reference (Pender, 2000). Normally however only a small subset is used. Below are the most commonly used QC flags. Please note that on some systems and file formats, e.g., NetCDF, it is not possible to store unsigned byte values. In this case, flags greater than 127 are stored as negative numbers. To convert them to unsigned integers, simply add 256.

| Signed | Unsigned | Description               | Data State | Operation Type    | Error Type                                |
|--------|----------|---------------------------|------------|-------------------|---|
| -123   | 133      | Bad (data are set to NaN) | Bad        | None              | Error Flagged by processor                |
| 0      | 0        | Good                      | Good       | None              | No error, data are good                   |
| -187   | 69       | Suspect (data unchanged)  | Suspect    | None              | Error flagged by processor                |
| -135   | 121      | Operator adjusted         | Suspect    | Manually adjusted | Data out of range                         |
| -115   | 141      | Data missing              | Bad        | None              | No data, missing for an unknown reason    |
| -53    | 203      | Not QC'd                  | No QC      | None              | Preliminary processing (calibration) only |
| -199   | 57       | Operator adjusted         | Good       | Manually Adjusted | Data out of range                         |

Table 3: QC flag descriptions

## 2.6 Final Dataset Files

The final datasets for publication and distribution: The navigation, meteorological and Thermosalinograph data are entered into the O&A divisional data warehouse. All data timestamps are in UTC. Please note that the csv files contain only the QC'd variables listed in [Table 4](#).

| File Name                                      | Description   |
|--|---|
| <b>IN2024_V01_UWY_5sec.csv</b>                 | 5-second resolution CSV format dataset of QC'd parameters                 |
| <b>IN2024_V01_UWY_10sec.csv</b>                | 10-second resolution CSV format (interpolated) dataset of QC'd parameters |
| <b>IN2024_V01_UWY_1min.csv</b>                 | 1-minute resolution CSV format (interpolated) dataset of QC'd parameters  |
| <b>IN2024_V01_UWY_5min.csv</b>                 | 5-minute resolution CSV format (interpolated) dataset of QC'd parameters  |
| <b>IN2024_V01_UWY.nc</b>                       | 5-second resolution NetCDF format full dataset including unQC'd data      |
| <b>IN2024_V01_UWY_TSGCal_BottleResults.csv</b> | TSG Salinity calibration sample bottle data                               |

Table 4: Final underway dataset files

### 3 References

Alix Post. (2023). *The RV Investigator. Voyage Plan IN2024\_V01* Retrieved from Marine National Facility: Voyage Plans and summaries: <https://mnf.csiro.au/en/Voyages/Voyage-Catalogue>

## 4 Appendices

### A.1 Underway Sensors

The table below contains the descriptions of the ship's underway sensors and NetCDF variables.

| Underway Data Instrument and Identifier                                      | Sensor Description   | Position                              | NetCDF variable         | QC  | Variable Description                              | Variable units                 |
|--|--|---------------------------------------|-------------------------|-----|---|--------------------------------|
| <b>Navigation Instruments:</b>   |  |                                       |                         |     |   |                                |
| <b>Seapath 330+ with Seatex MRU 5+ and FUGRO Seastar 3610 DGNSS receiver</b> | DGPS system providing position, attitude, velocity, acceleration and timing information. | Monkey Island & Bridge equipment room |                         |     |   |                                |
|  |  |                                       | Longitude               | yes | Longitude   | degrees East                   |
|  |  |                                       | Latitude                | yes | Latitude  | degrees North                  |
|  |  |                                       | speedOG                 | yes | Ship speed over ground                            | knots                          |
|  |  |                                       | courseOG                | yes | Ship course over ground                           | degrees                        |
|  |  |                                       | shipHeading             | yes | Heading of the ship                               | degrees                        |
|  |  |                                       | alt                     | no  | Altitude re: mean sea level (geoid)               | meters                         |
| <b>Northrup Grumman Sperry 4914-CA Navigat X MK1</b>                         | Gyrocompass  | Bridge                                |                         |     |   |                                |
|  |  |                                       | gyroHeading             | No  | Gyro Heading                                      | degrees                        |
| <b>Kongsberg Maritime Skipper DL850</b>                                      | 3 Axis doppler log - measuring vessel speed through water                                | Gondola                               | (no data)               |     |   |                                |
|  |  |                                       | longitudinalWaterSpeed  | No  | Longitudinal water speed                          | knots                          |
|  |  |                                       | transverseWaterSpeed    | No  | Transversal water speed                           | knots                          |
|  |  |                                       | longitudinalGroundSpeed | No  | Longitudinal ground speed                         | knots                          |
|  |  |                                       | transverseGroundSpeed   | No  | Transversal ground speed                          | knots                          |
|  |  |                                       | lockOnWater             | No  | Lock on water flag                                | n/a                            |
|  |  |                                       | lockonGround            | No  | Lock on the ground flag                           | n/a                            |
| <b>Seawater Instruments:</b>   |  |                                       |                         |     |   |                                |
| <b>Sea-Bird-SBE 21 TSG</b>   | Thermosalinograph (TSG)  | CTD Space                             |                         |     |   |                                |
|  |  |                                       | salinity                | Yes | Measures sea surface salinity                     | Practical Salinity Units (PSU) |
|  |  |                                       | tsgSensorTemp           | No  | Water temperature measurement in the TSG canister | degrees Celsius (degC)         |

|                                     |  |                       |                   |     |  |  |
|-------------------------------------|--|-----------------------|-------------------|-----|--|--|
| <b>Burkert 8045</b>                 | Flow meter   | CTD space             |                   |     |  |  |
|                                     |  |                       | tsgFlow           | No  | Flow rate of seawater through the TSG                                | L/min                                    |
| <b>Burkert 8045</b>                 | Flow meter   | Underway Seawater Lab |                   |     |  |  |
|                                     |  |                       | labMainFlow       | No  | Underway lab main seawater flow rate                                 | L/min                                    |
| <b>Kobold MIK-C</b>                 | Flow meter   | Underway Seawater Lab |                   |     |  |  |
|                                     |  |                       | labBranchFlow     | No  | Underway lab branch seawater flow rate                               | L/min                                    |
| <b>Sea-Bird - SBE 38</b>            | Remote Temperature Probe   | Port Drop Keel        |                   |     |  |  |
|                                     |  |                       | waterTemp         | Yes | Sea surface water temperature measurement                            | degrees Celsius (degC)                   |
| <b>Wet Labs Wetstar Fluorometer</b> | Fluorometer  | Underway Seawater Lab |                   |     |  |  |
|                                     |  |                       | fluorescence      | No  | Measures active phytoplankton biomass and chlorophyll concentrations | percentage of the full-scale voltage (%) |
| <b>CSIRO Hobart pCO2</b>            | Underway pCO <sub>2</sub> system measuring surface water CO <sub>2</sub> mole fraction | Underway Seawater Lab |                   |     |  |  |
|                                     |  |                       | equTemp           | No  | Equilibrator water temperature                                       | degrees Celsius (degC)                   |
|                                     |  |                       | XCO2              | No  | XCO2   | ppm                                      |
|                                     |  |                       | waterVapour       | No  | Water vapour   | mmol/mol                                 |
|                                     |  |                       | licorPressure     | No  | Licor pressure   | hPa                                      |
|                                     |  |                       | equPressure       | No  | Equilibrator pressure  | hPa                                      |
|                                     |  |                       | waterFlow         | No  | Water flow   | L/min                                    |
|                                     |  |                       | licorFlow         | No  | Licor flow   | mL/min                                   |
|                                     |  |                       | ventFlow          | No  | Vent Flow  | mL/min                                   |
|                                     |  |                       | condTemp          | No  | Condenser Temperature  | degrees Celsius (degC)                   |
|                                     |  |                       | pumpSpeed         | No  | CO2 Pump Speed   | L/min                                    |
| <b>Aanderaa Oxygen Optode 3835</b>  | Oxygen Sensor  | Underway Seawater Lab |                   |     |  |  |
|                                     |  |                       | do                |     | oxygen   | µM                                       |
|                                     |  |                       | doSaturation      |     | Air saturation   | percentage (%)                           |
|                                     |  |                       | optodeWaterTemp   |     | Optode water temperature   | degrees Celsius (degC)                   |
| <b>CSIRO Drop keel sensor</b>       | Measuring drop keel draft  | Port & starboard      |                   |     |  |  |
|                                     |  |                       | portKeelExtension |     | Port drop keel extension   | meters                                   |

|  |                                 |                      |                        |     |   |                        |
|--|---------------------------------|----------------------|------------------------|-----|---|------------------------|
|  |                                 |                      | starboardKeelExtension |     | Starboard drop keel extension                   | meters                 |
| <b>Meteorological Instruments:</b>     |                                 |                      |                        |     |   |                        |
| <b>Rotronic T&amp;RH HC2A-S3</b>       | Temperature and Humidity Sensor | Foremast (Starboard) |                        |     |   |                        |
|  |                                 |                      | stbdAirTemp            | Yes | Starboard air temperature measurement           | degrees Celsius (degC) |
|  |                                 |                      | stbdHumidity           | Yes | Starboard humidity measurement                  | percentage (%)         |
|  |                                 |                      | stbdDewPoint           | Yes | Starboard Dew Point                             | degrees Celsius (degC) |
| <b>Rotronic T&amp;RH HC2A-S3</b>       | Temperature and Humidity Sensor | Foremast (Port)      |                        |     |   |                        |
|  |                                 |                      | portAirTemp            | Yes | Port air temperature measurement                | degrees Celsius (degC) |
|  |                                 |                      | portHumidity           | Yes | Port humidity measurement                       | percentage (%)         |
|  |                                 |                      | portDewPoint           | Yes | Port Dew Point                                  | degrees Celsius (degC) |
| <b>Vaisala Ship's Barometer PTB330</b> | Atmospheric pressure            | Bridge Wing          | atmPressureBridge      | Yes | Atmospheric pressure measurement                | millibar (mbar)        |
| <b>Vaisala Ship's Barometer PTB330</b> | Atmospheric pressure            | Foremast             | atmPressure            | Yes | Atmospheric pressure measurement                | millibar (mbar)        |
| <b>RM Young Wind Sensor Type 05107</b> | Vane type wind sensor           | Foremast (Port)      |                        |     |   |                        |
|  |                                 |                      | portRelWindSpeed       | Yes | Wind speed relative to the ship                 | knots                  |
|  |                                 |                      | portRelWindDir         | Yes | Wind direction relative to the ship             | degrees                |
|  |                                 |                      | portTrueWindSpeed      | Yes | True wind speed, corrected for ship speed       | knots                  |
|  |                                 |                      | portTrueWindDir        | Yes | True wind direction, corrected for ship heading | degrees                |
|  |                                 |                      | maxWindGust            | Yes | True maximum wind gust corrected for ship speed | knots                  |
| <b>RM Young Wind Sensor Type 05108</b> | Vane type wind sensor           | Foremast (Starboard) |                        |     |   |                        |
|  |                                 |                      | stbdRelWindSpeed       | Yes | Wind speed relative to the ship                 | knots                  |
|  |                                 |                      | stbdRelWindDir         | Yes | Wind direction relative to the ship             | degrees                |
|  |                                 |                      | stbdTrueWindSpeed      | Yes | True wind speed, corrected for ship speed       | knots                  |
|  |                                 |                      | stbdTrueWindDir        | Yes | True wind direction, corrected for ship heading | degrees                |
| <b>Gill WindObserver II</b>            | Ultrasonic Wind Sensor          | Foremast             |                        |     |   |                        |

|                                       |                                     |                           |                         |     |  |                      |
|---------------------------------------|-------------------------------------|---------------------------|-------------------------|-----|--|----------------------|
|                                       |                                     | (Port)                    |                         |     |  |                      |
|                                       |                                     |                           | ultrasonicRelWindSpeed  | Yes | Wind speed relative to the ship  | knots                |
|                                       |                                     |                           | ultrasonicRelWindDir    | Yes | Wind direction relative to the ship  | degrees              |
|                                       |                                     |                           | ultrasonicTrueWindSpeed | Yes | True wind speed, corrected for ship speed and direction                      | knots                |
|                                       |                                     |                           | ultrasonicTrueWindDir   | Yes | True wind direction, corrected for ship speed and heading                    | degrees              |
| <b>RM Young Rain Gauge type 50202</b> | Syphoning Rain Sensor               | Foremast                  |                         |     |  |                      |
|                                       |                                     |                           | portRain                | Yes | Accumulated hourly rain  | mm                   |
|                                       |                                     |                           | stbdRain                | Yes | Accumulated hourly rain  | mm                   |
| <b>Eppley PIR</b>                     | Precision Infrared Radiometer       | Monkey Island (Starboard) |                         |     |  |                      |
|                                       |                                     |                           | stbdRadiometer          | Yes | Measure radiation in the band 4-100 micron, longwave radiation               | W/m <sup>2</sup>     |
| <b>Eppley PIR</b>                     | Precision Infrared Radiometer       | Monkey Island (Port)      |                         |     |  |                      |
|                                       |                                     |                           | portRadiometer          | Yes | Measure radiation in the band 4-100 micron, longwave radiation               | W/m <sup>2</sup>     |
| <b>Eppley PSP</b>                     | Precision Spectral Pyranometer      | Monkey Island (Starboard) |                         |     |  |                      |
|                                       |                                     |                           | stbdPyranometer         | Yes | Measure radiation in the band 0.2 - 4 micron, shortwave radiation            | W/m <sup>2</sup>     |
| <b>Eppley PSP</b>                     | Precision Infrared Radiometer       | Monkey Island (Port)      |                         |     |  |                      |
|                                       |                                     |                           | portPyranometer         | Yes | Measure radiation in the band 0.2 - 4 micron, shortwave radiation.           | W/m <sup>2</sup>     |
|                                       |                                     |                           |                         |     |  |                      |
| <b>LI-COR LI-190 Quantum Sensor</b>   | Photosynthetically Active Radiation | Monkey Island (Starboard) |                         |     |  |                      |
|                                       |                                     |                           | stbdPAR                 | Yes | measures radiation in the photosynthetically active region of 0.4-0.7 micron | μE/m <sup>2</sup> /s |
| <b>LI-COR LI-190 Quantum Sensor</b>   | Photosynthetically Active Radiation | Monkey Island (Port)      |                         |     |  |                      |
|                                       |                                     |                           | portPAR                 | Yes | measures radiation in the photosynthetically active region of 0.4-0.7 micron | μE/m <sup>2</sup> /s |
|                                       |                                     |                           |                         |     |  |                      |

|   |  |                                  |  |    |                                   |                        |
|---|--|----------------------------------|--|----|-----------------------------------|------------------------|
| <b>Uni-Southampton ISAR SST</b>                   | Radiation sea surface temperature  | Bridge Wing (Port)               |  |    |                                   |                        |
|   |  |                                  | isarWaterTemp                              | No | ISAR Water Temperature            | degrees Celsius (degC) |
| <b>Air Sampling Systems:</b>                      |  |                                  |  |    |                                   |                        |
| <b>CSIRO air sampling inlet</b>                   | Air inlet controller   | foremast                         |  |    |                                   |                        |
|   |  |                                  | inletBearing                               | No | Air sampling inlet bearing        | degrees                |
|   |  |                                  | trackingBearing                            | No | Tracking target bearing           | degrees                |
| <b>Thermo Scientific MAAP Model 5102</b>          | Multi-angle Absorption Photometer (MAAP)   | Aerosol Lab (air sampling inlet) |  |    |                                   |                        |
|   |  |                                  | blackCarbonConc                            | No | Concentration of black carbon     | µg/m <sup>3</sup>      |
|   |  |                                  | airFlow                                    | No | Air flow rate                     | litres per Hour (L/h)  |
| <b>Thermo Scientific Model 49i Ozone Analyzer</b> | Ozone Monitor  |                                  |  |    |                                   |                        |
|   |  |                                  | o3Ozone1                                   | No | Ozone measurement                 | ppb                    |
|   |  |                                  | ozone1Meterflags                           | No | Instrument specific quality flag  | n/a                    |
| <b>Thermo Scientific Model 49i Ozone Analyzer</b> | Ozone Monitor  |                                  |  |    |                                   |                        |
|   |  |                                  | o3Ozone2                                   | No | Ozone measurement                 | ppb                    |
|   |  |                                  | ozone2Meterflags                           | No | Instrument specific quality flag  | n/a                    |
| <b>Picarro Model G2301 CRDS Analyzer</b>          | Greenhouse Gas Spectrometer CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O Near IR Laser |                                  |  |    |                                   |                        |
|   |  |                                  | co2Dry                                     | No | CO <sub>2</sub> dry concentration | ppm                    |
|   |  |                                  | ch4Dry                                     | No | CH <sub>4</sub> dry concentration | ppm                    |
|   |  |                                  | H <sub>2</sub> O                           | No | Water concentration percentage    | percentage (%)         |
| <b>Depth Sounders:</b>                            |  |                                  |  |    |                                   |                        |
| <b>Kongsberg EM122 multibeam sounder</b>          |  | Gondola                          | depth                                      | No | Water depth,                      | meters                 |
| <b>Kongsberg EM710 multibeam sounder</b>          |  | Gondola                          | depth                                      | No | Water depth,                      | meters                 |
| <b>EK60, 18KHz sounder</b>                        |  | Port Drop Keel                   | Depth, (if not provided by EM122 or EM710) | No | Water depth                       | meters                 |

Table 5: Ship's underway sensors and NetCDF variables

## A.2 Location of Meteorological Instruments

| <b>Date:</b>   | 26/03/2019  |        |         |        |   |                                     |
|--|---|--------|---------|--------|---|-------------------------------------|
| <b>Surveyors:</b>  | Stuart Edwards  |        |         |        |   |                                     |
|  | Matt Boyd   |        |         |        |   |                                     |
|  | CSIRO GSM Team  |        |         |        |   |                                     |
| <b>Instrument:</b>   | Leica TCRP 1205+ Total Station AND extrapolation from drawings    |        |         |        |   |                                     |
| Sensors surveyed with respect to existing vessel coordinate system:  |   |        |         |        |   |                                     |
|  | X-axis is positive toward starboard and perpendicular to Y -axis  |        |         |        |   |                                     |
|  | Y-axis is positive forward and parallel to vessel centreline keel |        |         |        |   |                                     |
|  | Z-axis is positive upwards  |        |         |        |   |                                     |
| CRP is MRU5+ located in transceiver room on 1st platform deck  |   |        |         |        |   |                                     |
| MRU5+ is 2.066m to Starboard of the V/L centreline & 53.439m fwd from transom. (Obtained from Parker Maritime)   |   |        |         |        |   |                                     |
| ΔH of Load Line measured from 02 level with Plumbob and tape, 9m from 02 Deck. Height of 02 deck calculated to be 8.707m above CRP on 1st Plat deck. Load Line height datum below vessel CRP |   |        |         |        |   |                                     |
|  |   |        |         |        |   |                                     |
| ID   | Description   | X      | Y       | Z      | Comment   | Final Height Above Summer Load Line |
| LL   | Summer Load Line  | 7.222  | -10.695 | -0.293 | Waterline reference                               | 0.000                               |
| WS1  | Foremast Propeller Anemometer Stbd                                | -0.513 | 35.811  | 24.487 | Measured to base of sensor                        | 24.780                              |
| WS2  | Foremast Propeller Anemometer Port                                | -3.361 | 35.867  | 24.228 | Measured to base of sensor                        | 24.521                              |
| WS3  | Foremast Gill Ultrasonic Anemometer                               | -3.344 | 35.986  | 21.812 | Measured to base of sensor                        | 22.105                              |
| WS4  | Precipitation Sensor Siphoning Port (formerly called "Central")   | -2.621 | 35.999  | 21.260 | Measured to base of sensor                        | 21.553                              |
| WS10   | Monkey Island Radiometer Plate Stbd                               | -0.164 | -0.430  | 24.980 | Measured to centre bottom face of disc            | 25.273                              |
| WS11   | Monkey Island Radiometer Plate Port                               | -3.753 | -0.389  | 24.927 | Measured to centre bottom face of disc            | 25.220                              |
| WS12   | Bridge Digital Barometer  | -1.559 | -4.243  | 20.265 | Measured to centre of unit                        | 20.558                              |
| WS13   | SST Radiometer (Port Bridge Wing)                                 | -11.77 | -3.3    | 19.3   | Measured to centre of bottle (Taped Measurement)  | 19.593                              |
|  | Foremast T&RH Sensor (Port)                                       | -2.636 | 35.1    | 24.451 | Relative measurements and estimates from drawings | 24.744                              |
|  | Foremast T&RH Sensor (Starboard)                                  | -1.253 | 35.101  | 24.451 | Relative measurements and estimates from drawings | 24.744                              |
|  | Precipitation Sensor Siphoning (Starboard)                        | -1.241 | 35.101  | 21.260 | Relative measurements and estimates from drawings | 21.553                              |
|  | Foremast Digital Barometer  | -3.316 | 32.596  | 9.61   | Relative measurements and estimates from drawings | 9.903                               |

Table 6: Location of meteorological instruments mounted on RV Investigator

### A.3 Drop Keel Instrumentation Positioning

|                            | Reference Point                          | Vertical Offset in metres (positive up) |                    |              |                 |
|----------------------------|--|---|--------------------|--------------|-----------------|
|                            |  | Flush with hull                         | Flush with gondola | Intermediate | Fully extracted |
| Drop Keel Position         |  |   |                    |              |                 |
| <b>Drop Keel Extension</b> | <b>Base of Hull</b>                      | <b>0.00</b>                             | <b>-1.194</b>      | <b>-2.00</b> | <b>-4.00</b>    |
| Base of Hull               | Ship's Central reference Point (CRP)     | -6.54                                   |                    |              |                 |
| Base of Drop Keel          | CRP                                      | -6.54                                   | -7.73              | -8.54        | -10.54          |
| SBE38 SST Intake           | Base of Drop Keel                        | 0.30                                    |                    |              |                 |
| SBE38 SST Intake           | CRP                                      | -6.24                                   | -7.43              | -8.24        | -10.24          |
| Summer Load Line (SLL)     | CRP                                      | -0.29                                   |                    |              |                 |
| <b>SBE38 SST Intake</b>    | <b>SLL (i.e., Depth below waterline)</b> | <b>-5.95</b>                            | <b>-7.14</b>       | <b>-7.95</b> | <b>-9.95</b>    |
| TSG Intake                 | Base of Drop Keel                        | 0.54                                    |                    |              |                 |
| TSG Intake                 | CRP                                      | -6.00                                   | -7.19              | -8.00        | -10.00          |
| <b>TSG Intake</b>          | <b>SLL (i.e., Depth below waterline)</b> | <b>-5.71</b>                            | <b>-6.90</b>       | <b>-7.71</b> | <b>-9.71</b>    |

Table 7: Drop keel instrumentation positioning

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