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RV *Investigator* Underway Data Processing Report

Voyage ID	**IN2023_V05**
Voyage Title	Untangling the causes of change over 25 years in the southeast marine ecosystem
Depart	Hobart, 28 June 2023, 09:45
Return	Hobart, 30 July 2023, 08:00
Chief Scientist	Dr. Richard Little (CSIRO)
Data Processor	Vito Dirita (CSIRO – E&T Data Acquisition & Processing)

Document History

Date	Version	Author	Comments
28 August 2023	1.0	Vito Dirita	Draft Version
29 September 2023	1.1	Vito Dirita	Final Version

Contents

1 Summary

The marine waters of southeast Australia are one of a series of global ocean-warming hotspots. In this region, the ocean surface is warming at a rate four times the global average and many species have extended their distributions southward, with apparent changes in local abundance. Projections show that these changes will continue for the next century.

The region is home to a range of important economic activities such as fisheries, oil and gas production, and emerging renewable energy industries. It also contains nationally important amenities such as marine parks. The region's offshore marine parks were the first marine parks declared in the national network. They are experiencing the greatest human-induced pressures in the network but remain relatively poorly known.

Fishery and ecosystem assessments were last conducted in the region 25 years ago. This project will repeat the surveys to document changes and establish a new biological and environmental baseline. This will help us better understand what is changing in the region and why, and the impacts from climate change.

The main activities on this voyage will be to collect data on the demersal fish community composition, benthic habitat, water column, and prey fields. Equipment to be used includes the deep towed camera, demersal (marine life close to the seafloor) trawls and CTD (conductivity, temperature and depth) casts. Sampling will include using the CTD to collect eDNA for analysis.

This report describes the production of quality controlled underway data from RV *Investigator* voyage IN2023_V05.

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

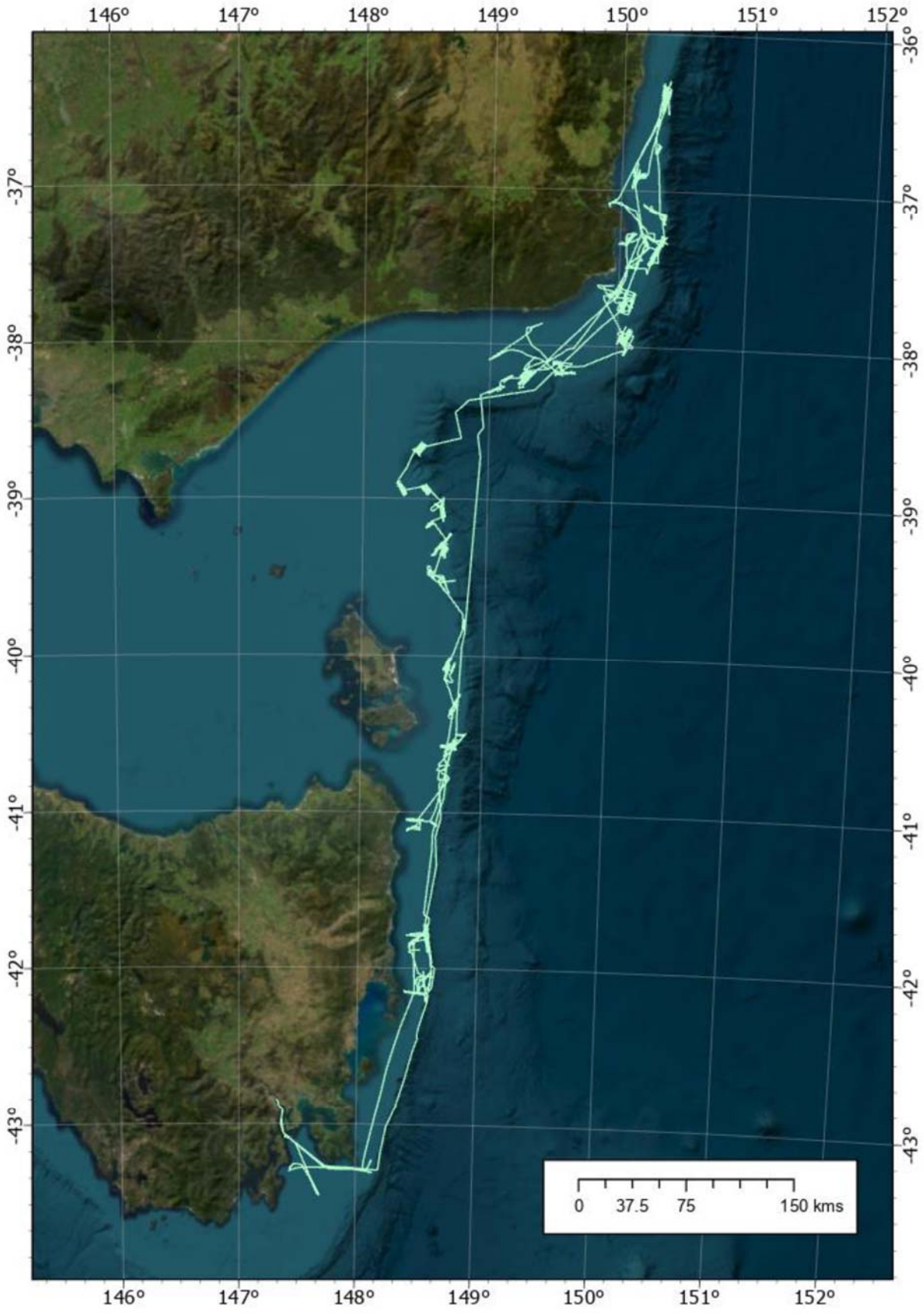

Figure 1: Voyage track

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 DGNSS 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 3 August 2023 (UTC) by running the Java application UWYMerger (version 1.8.1) with a data time range of 27-Jun-2023 23:44:45 to 29-Jul-2023 21:41:20 (UTC), the TECHSAS 1 system was used as the data source.

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_2 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 0.22C^{o}), 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 issues were found with the latitude and longitude data.

2.3.4 Humidity

Minor discrepancies between the port and starboard humidity sensor readings were noted, otherwise both sensors gave very close readings with a mean difference of 2.64. The differences are consistent with the discrepancies and variations in air temperature (refer to section 2.3.2) which reflect on the humidity reading variations seen in Table 1 in section 2.3.19.

2.3.5 Rain

On several occasions, the portRain gauge failed to fully drain (reset) to zero giving a small residual reading of 0.04mm, this value is withing the accuracy of the instrument and was left as good. Please note that differences that are less than the specified ±1 mm accuracy of the instrument are 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. Futhermore, 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 issues were found with the ship heading data.

2.3.9 Photosynthetically Active Radiation (PAR)

Some minor discrepancies between the port and starboard PAR sensor readings were noted and flagged as SUSPECT, otherwise both sensors gave very close readings. The portPAR appears to be zeroed at 1 $\mu E/m^2/s$ as opposed to zero, this is likely due to a rounding off from 0.6 to 1.0 caused by stray background noise.

2.3.10 Pyranometer

Some 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 (-4W/m^2), these readings are acceptable and within the specifications of the instrument.

2.3.11 Radiometer

Some minor discrepancies between the port and starboard Radiometer sensor readings were noted and flagged as SUSPECT, otherwise both sensors gave very close readings.

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 13 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. Futhermore, 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

No issues were found with the water temperature sensor readings.

2.3.14 Salinity

No issues were found with the salinity sensor readings. Please note that when the TSG pump is switched off (i.e., tsgFlow is near zero) then the salinity measurements become unreliable and 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 36 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 0.999996. The residual had a standard deviation (SD) of 0.003477 PSU (better than the required ≤ 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: IN2023_V05_*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 2.1 minutes (125 seconds) between the two data sets and a mean thermal increase of +0.220^{o}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 travelling at 10 knots and it takes 2.1 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 643 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 2.0m for the duration of the voyage, the ship's draft is nominally 6.0m, thus the TSG intake port is located 6.0m+2.0m (8.0m) 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	0.22	1.6	0.22	1.6	*degrees Celsius*
Humidity	2.64	12.2	2.64	12.2	*%RH*
Relative Wind Speed	1.75	34.81	1.59	28.84	*knots*
True Wind Speed	1.86	32.83	1.72	26.34	*knots*
Relative Wind Direction	8.66	179.83	8.58	178.69	*degrees*
True Wind Direction	9.48	179.63	9.42	179.63	*degrees*
PAR	28.18	963	27.95	963	$\mu E/m^2/s$
Pyranometer	10.66	480.8	10.54	480.8	W/m^2
Radiometer	2.49	81.1	2.47	29.5	W/m^2
Rain	0.01	0.94	0.01	0.94	*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	100	0	0	0
4	courseOG	courseOGQC	99.98	0	0	0.02
5	shipHeading	shipHeadingQC	99.92	0	0	0.08
6	portAirTemp	portAirTempQC	99.98	0	0	0.02
7	stbdAirTemp	stbdAirTempQC	99.98	0	0	0.02
8	portHumidity	portHumidityQC	99.98	0	0	0.02
9	stbdHumidity:	stbdHumidityQC	99.98	0	0	0.02
10	atmPressure:	atmPressureQC	99.98	0	0	0.02
11	portRelWindDir	portRelWindDirQC	99.93	0.01	0.04	0.02
12	stbdRelWindDir	stbdRelWindDirQC	99.92	0.01	0.05	0.02
13	portTrueWindDir	portTrueWindDirQC	99.93	0	0.05	0.02
14	stbdTrueWindDir	stbdTrueWindDirQC	99.95	0	0.04	0.02
15	portRelWindSpeed	portRelWindSpeedQC	99.92	0	0.06	0.02
16	stbdRelWindSpeed	stbdRelWindSpeedQC	99.03	0	0.95	0.02
17	portTrueWindSpeed	portTrueWindSpeedQC	99.93	0	0.05	0.02
18	stbdTrueWindSpeed	stbdTrueWindSpeedQC	99.07	0	0.92	0.02
19	maxWindGust	maxWindGustQC	99.94	0	0.05	0.01
20	portRain	portRainQC	99.99	0	0	0.01
21	stbdRain	stbdRainQC	99.99	0	0	0.01
22	portPAR	portPARQC	99.93	0.06	0	0.01
23	stbdPAR	stbdPARQC	99.94	0.04	0	0.01
24	portPyranometer	portPyranometerQC	99.95	0.03	0	0.01
25	stbdPyranometer	stbdPyranometerQC	99.92	0.06	0	0.01
26	portRadiometer	portRadiometerQC	99.93	0.05	0	0.01
27	stbdRadiometer	stbdRadiometerQC	99.99	0	0	0.01
28	ultrasonicRelWindSpeed	ultrasonicRelWindSpeedQC	98.45	0	1.54	0.01
29	ultrasonicTrueWindSpeed	ultrasonicTrueWindSpeedQC	98.77	0	1.21	0.01
30	ultrasonicRelWindDir	ultrasonicRelWindDirQC	99.32	0.07	0.59	0.01
31	ultrasonicTrueWindDir	ultrasonicTrueWindDirQC	99.9	0.01	0.08	0.01
32	salinity	salinityQC	95.27	0	0.31	4.42
33	waterTemp	waterTempQC	99.72	0	0	0.28

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
IN2023_V05_UWY_5sec.csv	5-second resolution CSV format dataset of QC'd parameters
IN2023_V05_UWY_10sec.csv	10-second resolution CSV format (interpolated) dataset of QC'd parameters
IN2023_V05_UWY_1min.csv	1-minute resolution CSV format (interpolated) dataset of QC'd parameters
IN2023_V05_UWY_5min.csv	5-minute resolution CSV format (interpolated) dataset of QC'd parameters
IN2023_V05_UWY.nc	5-second resolution NetCDF format full dataset including unQC'd data
IN2023_V05_UWY_TSGCal_BottleResults.csv	TSG Salinity calibration sample bottle data

Table 4: Final underway dataset files

3 References

Alix Post. (2023). *The RV Investigator. Voyage Plan* IN2023_V05 Retrieved from Marine National Facility: Voyage Plans and summaries: https://mnf.csiro.au/en/Voyages/Voyage-Catalogue

Pender, L. (2000). *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

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
Navigation Instruments:						
Seapath 330+ with Seatex MRU 5+ and FUGRO Seastar 3610 DGNSS receiver	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
Northrup Grumman Sperry 4914-CA Navigat X MK1	Gyrocompass	Bridge				
			gyroHeading	No	Gyro Heading	degrees
Kongsberg Maritime **Skipper DL850**	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
Seawater Instruments:						
Sea-Bird-SBE 21 TSG	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)

Burkert 8045	Flow meter	CTD space				
			tsgFlow	No	Flow rate of seawater through the TSG	L/min
Burkert 8045	Flow meter	Underway Seawater Lab				
			labMainFlow	No	Underway lab main seawater flow rate	L/min
Kobold MIK-C	Flow meter	Underway Seawater Lab				
			labBranchFlow	No	Underway lab branch seawater flow rate	L/min
Sea-Bird - SBE 38	Remote Temperature Probe	Port Drop Keel				
			waterTemp	Yes	Sea surface water temperature measurement	degrees Celsius (degC)
Wet Labs Wetstar Fluorometer	Fluorometer	Underway Seawater Lab				
			fluorescence	No	Measures active phytoplankton biomass and chlorophyll concentrations	percentage of the full-scale voltage (%)
CSIRO Hobart pCO2	Underway pCO_2 system measuring surface water CO_2 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
Aanderaa Oxygen Optode 3835	Oxygen Sensor	Underway Seawater Lab				
			do		oxygen	µM
			doSaturation		Air saturation	percentage (%)
			optodeWaterTemp		Optode water temperature	degrees Celsius (degC)
CSIRO Drop keel sensor	Measuring drop keel draft	Port & starboard				
			portKeelExtension		Port drop keel extension	meters

			starboardKeelExtension		Starboard drop keel extension	meters
Meteorological Instruments:						
Rotronic T&RH HC2A-S3	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)
Rotronic T&RH HC2A-S3	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)
Vaisala Ship's Barometer PTB330	Atmospheric pressure	Bridge Wing	atmPressureBridge	Yes	Atmospheric pressure measurement	millibar (mbar)
Vaisala Ship's Barometer PTB330	Atmospheric pressure	Foremast	atmPressure	Yes	Atmospheric pressure measurement	millibar (mbar)
RM Young Wind Sensor Type 05107	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
RM Young Wind Sensor Type 05108	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
Gill WindObserver II	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
RM Young Rain Gauge type 50202	Syphoning Rain Sensor	Foremast				
			portRain	Yes	Accumulated hourly rain	mm
			stbdRain	Yes	Accumulated hourly rain	mm
Eppley PIR	Precision Infrared Radiometer	Monkey Island (Starboard)				
			stbdRadiometer	Yes	Measure radiation in the band 4-100 micron, longwave radiation	W/m^2
Eppley PIR	Precision Infrared Radiometer	Monkey Island (Port)				
			portRadiometer	Yes	Measure radiation in the band 4-100 micron, longwave radiation	W/m^2
Eppley PSP	Precision Spectral Pyranometer	Monkey Island (Starboard)				
			stbdPyranometer	Yes	Measure radiation in the band 0.2 - 4 micron, shortwave radiation	W/m^2
Eppley PSP	Precision Infrared Radiometer	Monkey Island (Port)				
			portPyranometer	Yes	Measure radiation in the band 0.2 - 4 micron, shortwave radiation.	W/m^2
LI-COR LI-190 Quantum Sensor	Photosynthetically Active Radiation	Monkey Island (Starboard)				
			stbdPAR	Yes	measures radiation in the photosynthetically active region of 0.4-0.7 micron	µE/m^2/s
LI-COR LI-190 Quantum Sensor	Photosynthetically Active Radiation	Monkey Island (Port)				
			portPAR	Yes	measures radiation in the photosynthetically active region of 0.4-0.7 micron	µE/m^2/s

Uni-Southampton ISAR SST	Radiation sea surface temperature	Bridge Wing (Port)				
			isarWaterTemp	No	ISAR Water Temperature	degrees Celsius (degC)
Air Sampling Systems:						
CSIRO air sampling inlet	Air inlet controller	foremast				
			inletBearing	No	Air sampling inlet bearing	degrees
			trackingBearing	No	Tracking target bearing	degrees
Thermo Scientific MAAP Model 5102	Multi-angle Absorption Photometer (MAAP)	Aerosol Lab (air sampling inlet)				
			blackCarbonConc	No	Concentration of black carbon	µg/m^3
			airFlow	No	Air flow rate	litres per Hour (L/h)
Thermo Scientific Model 49i Ozone Analyzer	Ozone Monitor					
			o3Ozone1	No	Ozone measurement	ppb
			ozone1Meterflags	No	Instrument specific quality flag	n/a
Thermo Scientific Model 49i Ozone Analyzer	Ozone Monitor					
			o3Ozone2	No	Ozone measurement	ppb
			ozone2Meterflags	No	Instrument specific quality flag	n/a
Picarro Model G2301 CRDS Analyzer	Greenhouse Gas Spectrometer CO2, CH4, H2O Near IR Laser					
			co2Dry	No	CO2 dry concentration	ppm
			ch4Dry	No	CH4 dry concentration	ppm
			H2O	No	Water concentration percentage	percentage (%)
Depth Sounders:						
Kongsberg EM122 multibeam sounder		Gondola	depth	No	Water depth,	meters
Kongsberg EM710 multibeam sounder		Gondola	depth	No	Water depth,	meters
EK60, 18KHz sounder		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

Date:	26/03/2019
Surveyors:	Stuart Edwards
	Matt Boyd
	CSIRO GSM Team
Instrument:	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)**			
Drop Keel Position		**Flush with hull**	**Flush with gondola**	**Intermediate**	**Fully extracted**
Drop Keel Extension	**Base of Hull**	**0.00**	**-1.194**	**-2.00**	**-4.00**
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			
SBE38 SST Intake	**SLL (i.e., Depth below waterline)**	**-5.95**	**-7.14**	**-7.95**	**-9.95**
TSG Intake	Base of Drop Keel	0.54			
TSG Intake	CRP	-6.00	-7.19	-8.00	-10.00
TSG Intake	**SLL (i.e., Depth below waterline)**	**-5.71**	**-6.90**	**-7.71**	**-9.71**

Table 7: Drop keel instrumentation positioning

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