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RV *Investigator* Triaxus Data Processing Report

Voyage ID	**IN2024_V01**
Voyage Title	Multidisciplinary Investigations of the Southern Ocean (MISO): Linking Physics, Biochemistry, Plankton, Aerosols, Clouds, And Climate
Depart	Hobart, 1 January 2024, 21:00 UTC
Return	Fremantle, 4 March 2024, 02:20 UTC
Chief Scientist	Annie Foppert (UTAS) & Steve Rintoul (CSIRO)
Data Processor	Francis Chui (CSIRO – E&T Data Acquisition & Processing)

Document History

Date	Version	Author	Comments
30 April 2024	1.0	Francis Chui	Initial version
22 May 2024	1.1	Francis Chui	Added CTD unit #

Contents

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 Triaxus data from RV *Investigator* voyage IN2024_V01.

5 Triaxus tows were conducted. The focus of Triaxus tows on this voyage was in support of the biology team to provide underway measurement within proximity of process stations where experiments were taking place.

Pressure, conductivity, temperature, and dissolved oxygen data were gathered from duplicate sensors using a Seabird SBE9*plus* CTD. Also carried on the Triaxus hull were a cosine Photosynthetically Active Radiation (PAR) sensor, a transmissometer, an ECO Triplet (optical backscatter, CDOM fluorometer and chlorophyll fluorometer) and a Laser Optical Plankton Counter (LOPC). Additionally, the MNF-supplied a Sea-Bird Scientific SUNA V2 nitrate sensor.

Tow 3 was abandoned prior to the commencement of undulations due to a significant tension spike (2.5T) being detected at the towed body winch. The standard procedure of vehicle retrieval and termination inspection was conducted.

On each tow, only data from legs where the Triaxus was vertically undulating regularly were processed. Data from deployment into the water, turns, and retrieval were also gathered but not further processed except to provide surface pressure references for the undulation legs. See Appendix A.1 for definitions and example usage of common terms employed here and throughout this report to describe Triaxus tow components and their associated data.

Pressure, conductivity, temperature, and dissolved oxygen sensor data were converted to calibrated units. Spikes and out-of-range values were removed, and primary sensor data were compared to secondary sensor data. PAR, transmissometer, ECO Triplet and SUNA nitrate data were combined into the dataset. LOPC data were gathered but are not processed or published with this report.

Published data have been grouped into 1-decibar bins. Both primary and secondary CTD sensors were reliable, so the final dataset uses the primary CTD sensor values in the default data variables (i.e., variables *without* "_2" appended).

On this voyage all tows were made up of legs that were sufficiently short to be recorded in single files. As such, a "leg" is the same as a "section" for all tows in this voyage.

The published data consist of:

- along-track time-series data for each leg
- synthetic interpolated vertical casts for each undulation peak and trough of each leg
- interpolated sectional plots of various sensor data taken from along-track time-series data for each leg.

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

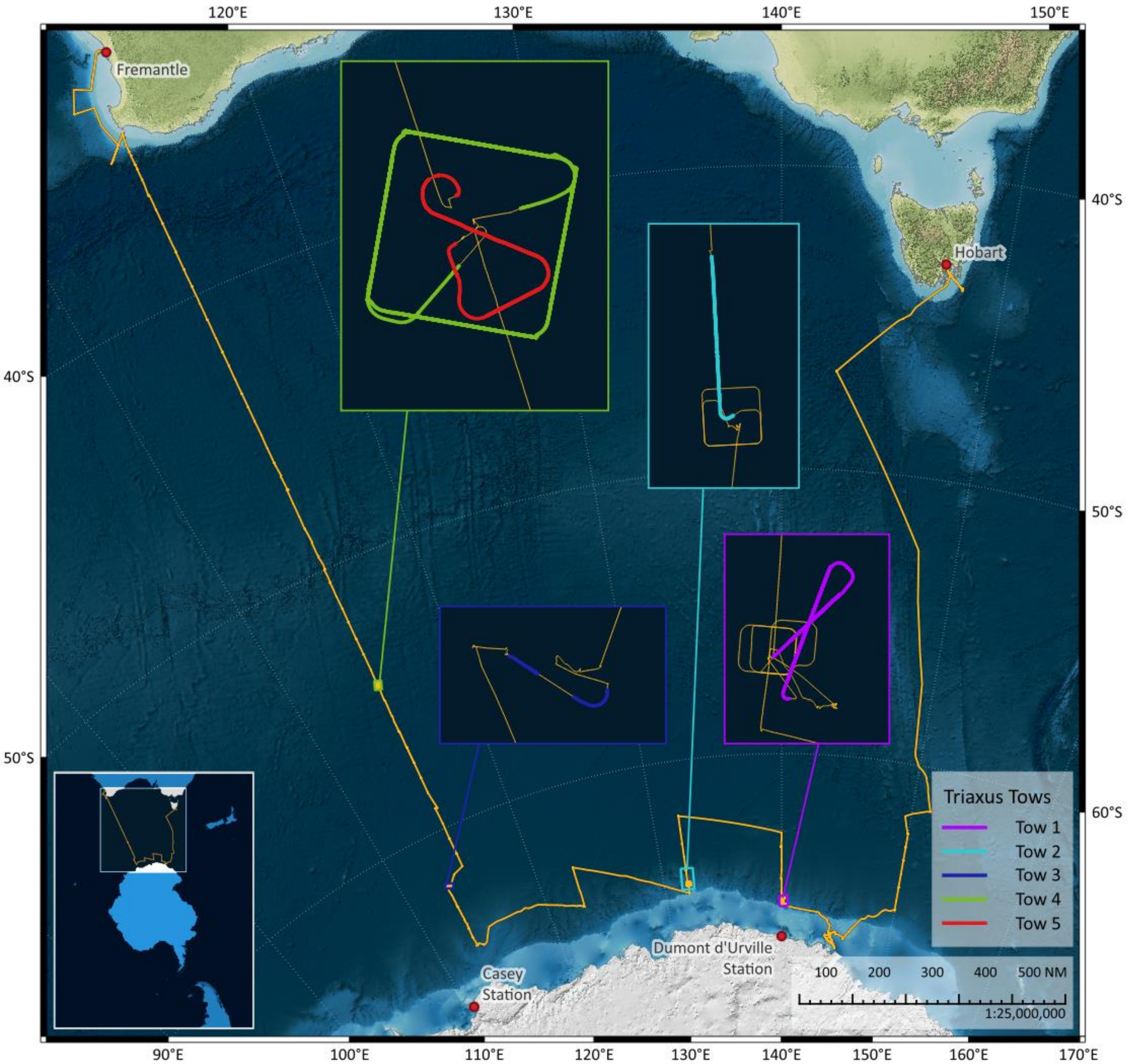

Figure 1: Voyage track with Triaxus tows.

2 Data Processing

2.1 Background Information

5 Triaxus tows were conducted, divided in the CTD acquisition software, Seasave, into 32 files. Flight data from the MacArtney Triaxus were logged containing pitch, roll, altimeter, and cable length.

The instrumentation used for the deployments is detailed in Table 1.

Available data variables are described in Appendix A.2.

Triaxus Hull Number: 003 (Serial Number S1712880)

Sensor Description	Data Channel	SBE9 Connector	Model	Serial Number
CTD			SBE9*plus* V2	1039 (#22)
Primary Temperature		JB1	SBE3*plus*	4722
Primary Conductivity		JB2	SBE4C	4426
Primary Pump		JB3	SBE5	9417
Secondary Temperature		JB4	SBE3*plus*	6130
Secondary Conductivity		JB5	SBE4C	4664
Secondary Pump		JB3	SBE5	11393
Primary Dissolved Oxygen	A0	JT2	SBE43	3154
Secondary Dissolved Oxygen	A1	JT2	SBE43	1794
PAR	A2	JT3	QCP2300HP	70111
Transmissometer	A3	JT3	CSTAR	CST-1735DR
ECO Triplet	Payload 2 (12V)		FLBBCD2K	5038
Nitrate	Payload 3 (12V)		Satlantic SUNA V2	1891
LOPC	Payload 7 (12V)		Rolls Royce LOPC-1xT-3	11025
Iridium Beacon	-	-	Xeos Apollo 3	132

Table 1: Triaxus sensor configuration on IN2024_V01

The raw CTD data were collected in SBE SeaSave version 7.26.7.110, converted to scientific units using SBE Data Processing version 7.26.7.129 and written to NetCDF format files with CNV_to_Scan (cnv_to_scan_ui2.py, from the private CSIRO MNF Data Acquisition and Processing “marinetech” git repository) for processing using the MATLAB-based CapPro package.

The CapPro software version 2.12 was used to apply automated QC and preliminary processing to the data. This included spike removal, identification of water entry and exit times, conductivity sensor lag corrections, conductivity cell thermal inertia corrections and the determination of the pressure offsets from the on-deck pressure before and after the tow. The automatically determined pressure offsets and in-water points were inspected and verified during data processing.

Below are descriptions of the tows:

Tow 1

- Objective
  - First process station after following drifter with RVI for 12 hours, we commenced the deployment of the Triaxus with a plan to tow in a figure 8 pattern.
- Leg 1
  - Deployment
- Leg 2
  - Stopped undulations and turn.
- Leg 3
  - Started undulations after turn.
- Leg 4
  - Stopped undulations and recovery.

Tow 2

- Objective
  - Commenced Triaxus deployment as we approached second the process station.
- Leg 1
  - Deployment and Undulations
- Leg 2
  - Turn and Recovery

Tow 3

- Objective
  - Deployed Triaxus after superstation deployment of ISP and before full depth TMR.
- Leg 1
  - Deployment and attempt to start undulations.
- Leg 2
  - No data acquisition while attempting to fix issues.
- Leg 3
  - Recovery.

Tow 4

- Objective
  - Deployed Triaxus circling drifter in a square pattern.
- Leg 1
  - Deployment and first undulation
- Leg 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
  - Continue undulations.
- Leg 3, 5, 7, 9, 11, 13, 15, 17, 19
  - Stopped undulation for turn.

- Leg 21
  - Recovery

Tow 5

- Objective
  - Deployed Triaxus after shallow TMR, ISP and bongo net tows in a figure eight pattern.
- Leg 1
  - Deployment and turn with commencement of undulations.
- Leg 2
  - Continued undulations.
- Leg 3
  - Recovery.

2.2 Sensor Correction

2.2.1 Pressure Sensor Location

The location of the pressure sensor in the front of the upper-port nacelle (red dot in Figure 2) relative to the C/T sensor pairs (blue squares in Figure 2) is defined through orthogonal axes XYZ (origin at C/T sensors) with X positive forward, Z positive up and Y positive to port, as indicated in Figure 2. Contrary to the Triaxus manual specification, this Triaxus has the Primary C/T pair on the port side and the Secondary C/T pair the starboard side, as pictured.

Using pitch (rotation around Y axis, positive nose up) and roll (rotation around X axis, positive clockwise looking forward) from the Triaxus flight data it is possible to correct the pressure at each sensor location.

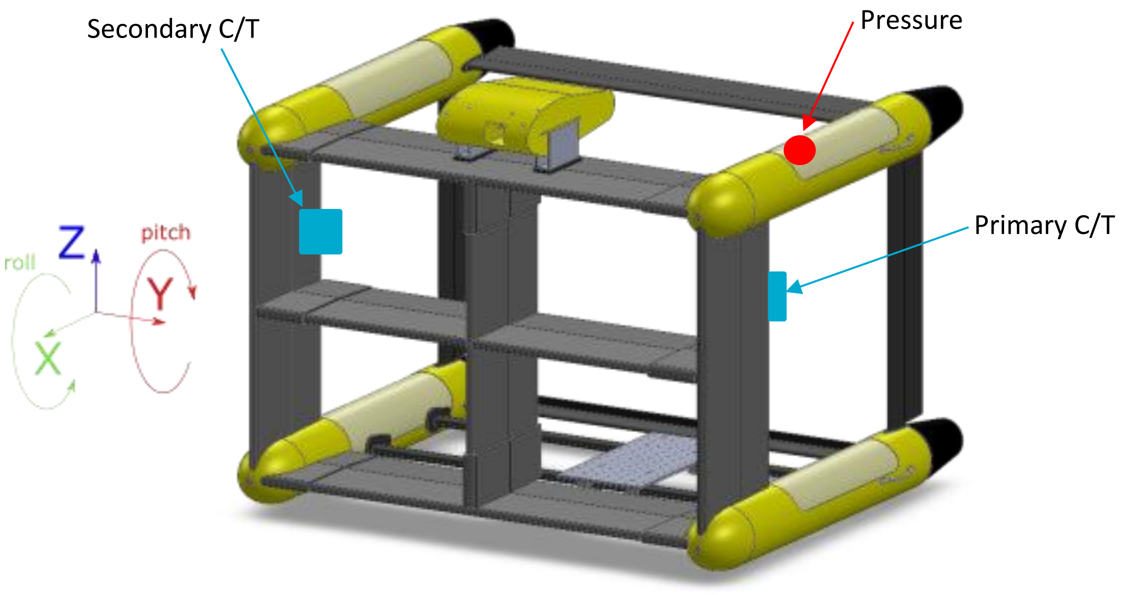

Figure 2: Triaxus General Arrangement. Pressure and C/T sensor locations approximate.

The pressure sensor location correction *was* applied in this instance. For reference, the pressure sensor location relative to each conductivity and temperature sensor pair for this voyage was as follows:

Origin	Vertical (Z) offset (m)	Fore / Aft (X) offset (m)	Port / Starboard (Y) offset (m)
Secondary C/T (starboard)	0.3	-0.45	1.68
Primary C/T (port)	0.3	-0.45	0.05

Table 2: Pressure sensor location relative to the C/T sensors (origins)

2.2.2 Thermal Inertia Correction

The temperature of the boundary layer water passing through the conductivity cell lags the temperature of the in-situ water due to the thermal mass of the cell. Since derived salinity is strongly dependent upon temperature, to derive correct salinity the apparent temperature of the water in the cell is required. To derive the apparent temperature given the in-situ temperature we assume a fraction of the water (belonging to the boundary layer) is lagged by a time constant. After extensive testing it has been determined that a good correction is achieved using two water fractions, 0.013 and 0.007, lagged by 7 and 1 seconds respectively.

2.3 Other Sensors

The Wetlabs C-Star transmissometer was used for all tows. The transmissometer has been calibrated to give nominal outputs of 0-100 full scale deflection. These data have been included in the output files.

The Biospherical PAR sensor was used for all tows. The PAR sensor has been calibrated to give output in µE/m²/s. These data have been included in the output files. Time of day and environmental factors, such as sea state and cloud cover, impact these readings. In periods of darkness these data will be zero.

The ECO Triplet sensor array and SUNA nitrate sensor were used for all tows. Both ECO Triplet and SUNA nitrate data have been merged into the averaged data products.

The LOPC was used for all tows. The raw data have not been merged into any data products, and no processing has been performed on the LOPC data.

2.4 Bad Data Detection

The range limits and maximum second differences for sensors connected to the SBE9*plus* A/D channels were configured in CapPro and written to the NetCDF file. Typical limits used for each sensor's range and maximum second difference are in Table 3.

ECO Triplet limits are set in CapPro and were found by examining the data from past voyages.

Sensor	Units	Range minimum	Range maximum	Max. Second Difference
Pressure	dbar	-7	6500	0.5
Temperature	°C	-10	40	0.05
Conductivity	S/m	-0.01	7	0.01
Dissolved Oxygen	µmol/L	-0.1	500	0.5
Transmissometer	%	80	100	0.5
PAR	µE/m^2/s	0.0	0.2	0.01
CDOM	ppb	0	2500	1
Optical Backscatter	m^{-1}	0	0.5e-3	1e-4
Chlorophyll	µg/L	0	1.2	0.1

Table 3: Sensor limits for bad data detection

Data found to be out of range or having a second difference above the maximum second difference were flagged as bad and filtered out by CapPro.

2.5 Averaging

Data were first binned 'along the track' into 1-dbar bins or 10-second bins for each leg in the NetCDF time-series data files. Binning is typically done over pressure, however in cases where the Triaxus is only moving horizontally a bin is taken every 10 seconds. The binned values were calculated by applying a linear, least-squares fit as a function of pressure to the sensor data for each bin, using this to interpolate the value for the bin mid-point. This method is used to avoid possible biases which would result from averaging with respect to time.

2.5.1 Vertical Cast Creation

'Vertical casts' were created from the along-track average files. A vertical cast represents a vertical column of data points geographically located at the minimum and maximum pressure points of an undulation. Data for a vertical cast is derived by interpolating between the binned data points on the upcast and downside of either side of the vertical cast.

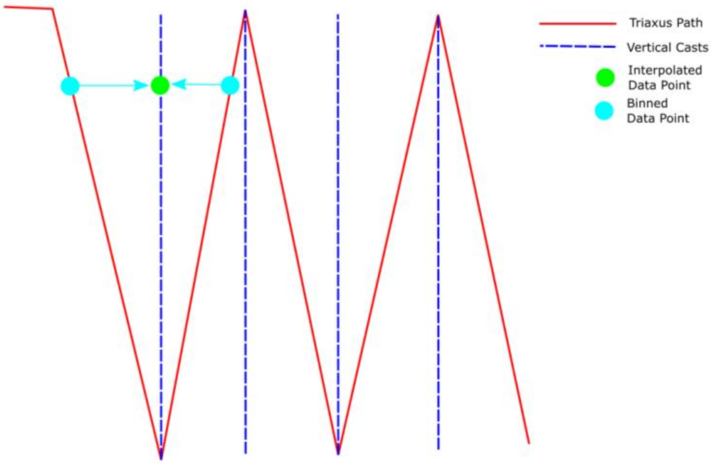

Figure 3: Vertical cast creation.

2.5.2 Vehicle Position Correction

The position of the Triaxus was estimated using ship's position, cable length, pressure, and time-weighted previous estimated positions.

2.5.3 Quality Control Flags

Each binned variable is assigned a quality control (QC) flag. The QC flagging scheme is described in Appendix A.3.

For each bin, for each variable, a QC Flag value is calculated from the data used to calculate that bin value. The QC Flag for a derived value (e.g., salinity or dissolved oxygen) is set to the worst QC Flag from the variables used in the derivation.

2.6 Significant Data Issues

After a software crash and restart, Tow 3 was abandoned due to tension spike of 2.5T on commencement of undulation. Triaxus was recovered to inspect termination for damage.

Table 4 notes the mean and maximum absolute difference between the primary and secondary Triaxus CTD sensor average data for each leg and confirms stable statistical variability between the two sensor sets through the deployments during undulations. Figure 4, Figure 5, Figure 6, and Figure 7 show box plots of sensor differences for temperature, conductivity, dissolved oxygen and calculated salinity (PSS-78).

		Mean Absolute Difference Primary to Secondary			Maximum Absolute Difference Primary to Secondary		
Tow	Leg	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (µM)	Temperature (°C)	Salinity (PSU)	Dissolved Oxygen (µM)
1	**1**	**0.00657**	**0.02402**	**8.67277**	**0.21160**	**0.82219**	**181.22400**
1	2	0.00230	0.00428	3.35807	0.06430	0.04464	7.38498
1	**3**	**0.00401**	**0.00472**	**3.41208**	**0.43180**	**0.18951**	**9.60400**
1	4	0.00234	0.00425	3.48928	0.14440	0.04849	7.35300
2	**1**	**0.00853**	**0.01192**	**3.13371**	**0.60040**	**31.40599**	**82.55502**
2	2	0.00325	0.00452	3.49195	0.20760	0.32335	5.70602
3	1	0.03713	12.87060	7.37183	24.53880	306539.69589	6236.37094
3	2	0.01061	101.47111	4.58500	24.94250	4638415.19421	3864.25989
4	1	0.02543	0.03030	3.57743	0.41510	33.31486	117.53998
4	**2**	**0.00346**	**0.00653**	**2.83439**	**0.19380**	**0.16034**	**8.70798**
4	3	0.00629	0.00694	3.05085	0.48070	0.11789	9.07999
4	**4**	**0.00361**	**0.00572**	**2.79557**	**0.22190**	**0.12555**	**6.00000**
4	5	0.00892	0.00613	2.77330	0.16770	0.05910	5.16098
4	**6**	**0.00457**	**0.00535**	**2.73996**	**0.19980**	**0.11814**	**6.48599**
4	7	0.00223	0.00515	2.55791	0.04310	0.02092	3.67999
4	**8**	**0.00362**	**0.00527**	**2.77542**	**0.16760**	**0.23693**	**6.10101**
4	9	0.00903	0.00526	2.71752	0.10630	0.04622	4.47101
4	**10**	**0.00356**	**0.00511**	**2.77341**	**0.15610**	**0.14304**	**5.74100**
4	11	0.00673	0.00565	2.94823	0.18180	0.06911	7.06500
4	**12**	**0.00336**	**0.00589**	**2.79536**	**0.12090**	**0.48463**	**5.83200**
4	13	0.00825	0.00577	2.74848	0.12880	0.04841	3.88501
4	**14**	**0.00392**	**0.00551**	**2.70267**	**0.16640**	**0.07599**	**5.96701**
4	15	0.00206	0.00518	2.60120	0.02070	0.01474	3.63699
4	**16**	**0.00374**	**0.00522**	**2.72306**	**0.36390**	**0.14958**	**6.65201**
4	17	0.01542	0.00563	2.64347	0.16390	0.08147	4.93100
4	**18**	**0.00366**	**0.00505**	**2.76894**	**0.12040**	**0.09099**	**7.07800**
4	19	0.00495	0.00474	2.89343	0.08910	0.03850	4.35703
4	**20**	**0.00372**	**0.00500**	**2.77580**	**0.16040**	**0.10169**	**6.32300**
4	21	0.00585	0.00490	2.65334	0.13450	0.69044	7.13800
5	1	0.02300	3.18202	0.02545	1.95590	4.49035	135.81400
5	**2**	**0.00476**	**0.00652**	**2.71343**	**0.29070**	**0.14231**	**7.82901**
5	3	0.08588	3.13811	0.04438	1.29920	5.18017	97.84900

Table 4: Mean and maximum absolute difference between primary and secondary CTD sensors. Suspect legs highlighted in red and legs with undulations in bold.

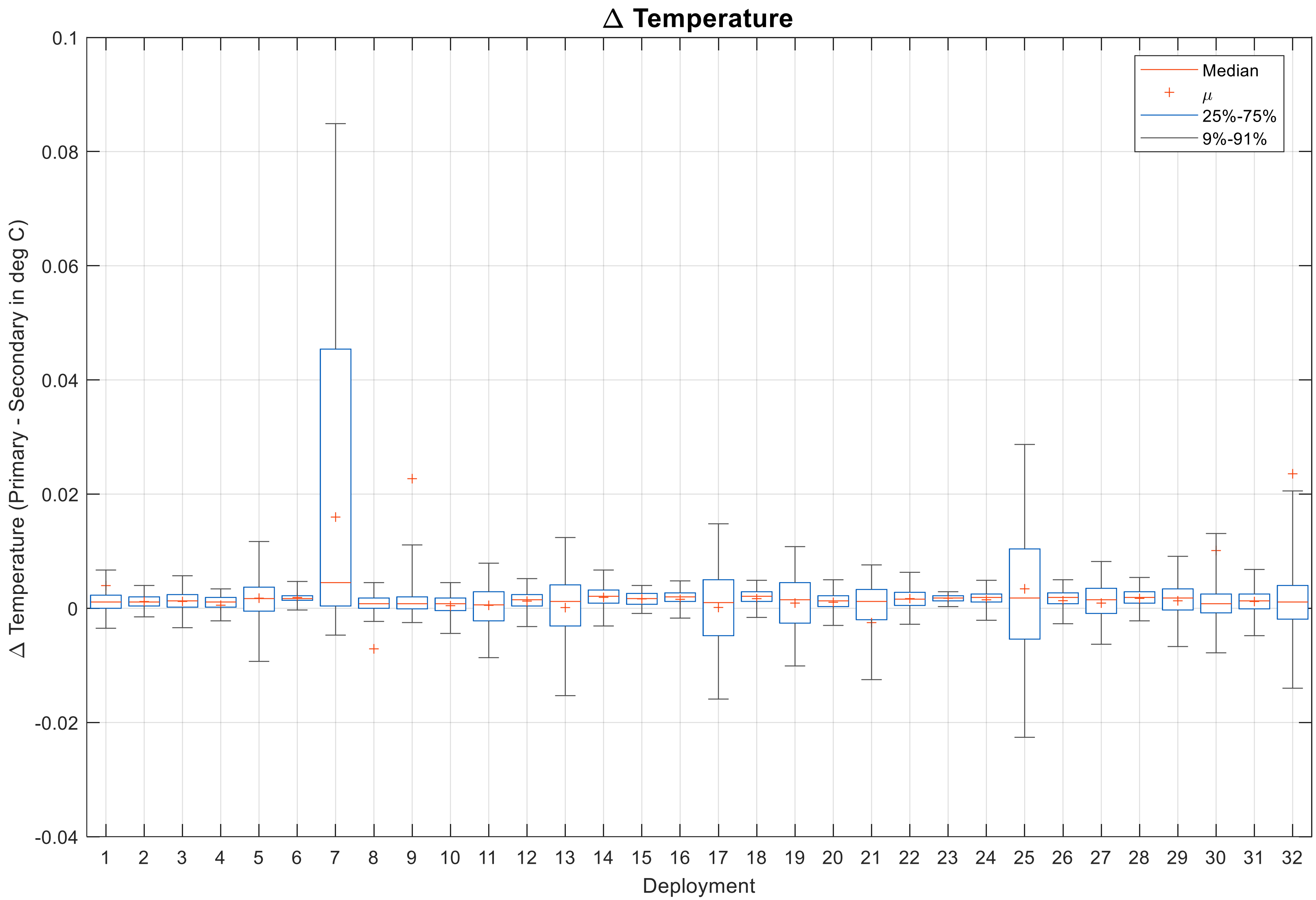

Figure 4 Box plots of the difference between primary and secondary temperature sensors.

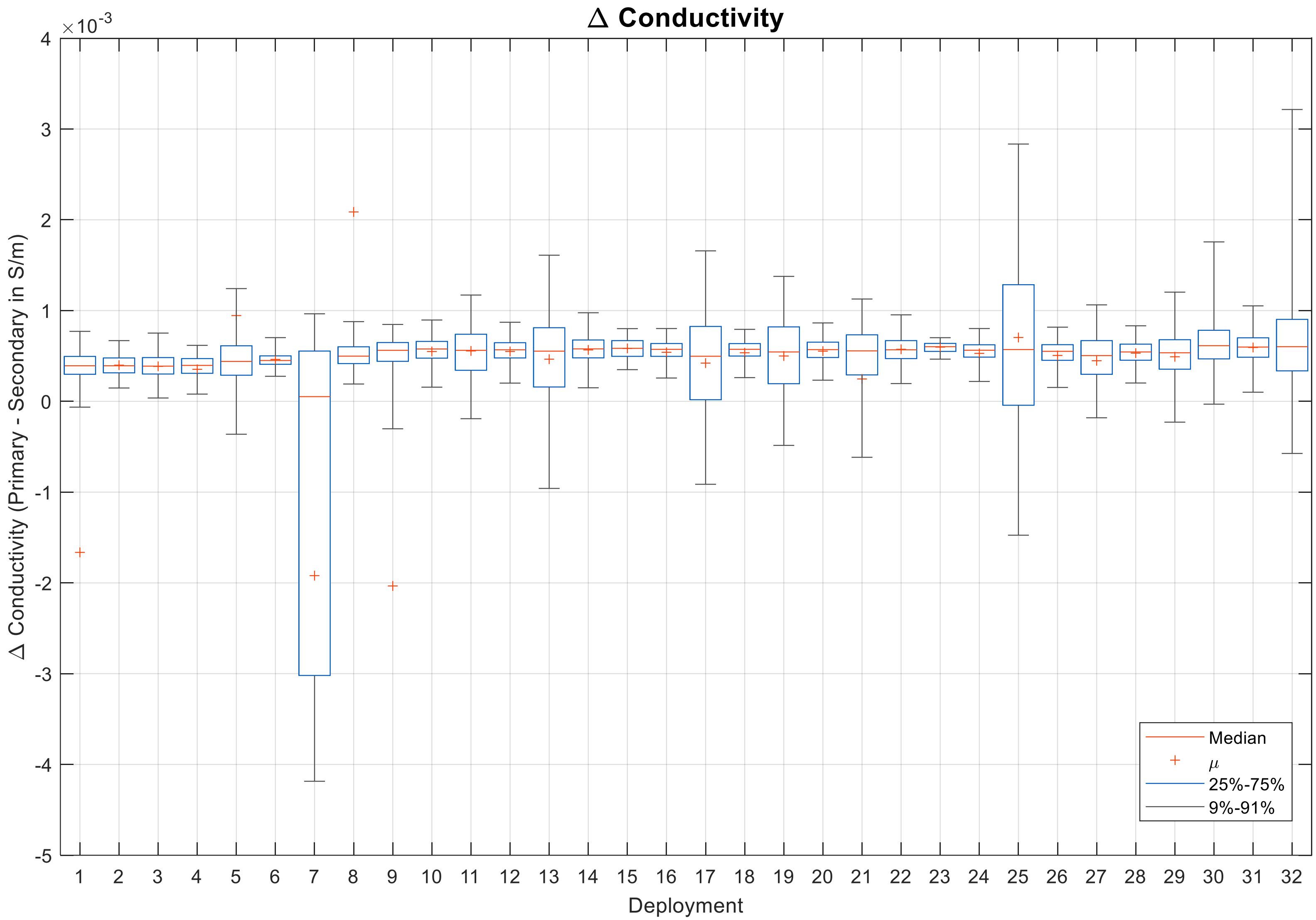

Figure 5 Box plots of the difference between primary and secondary conductivity sensors.

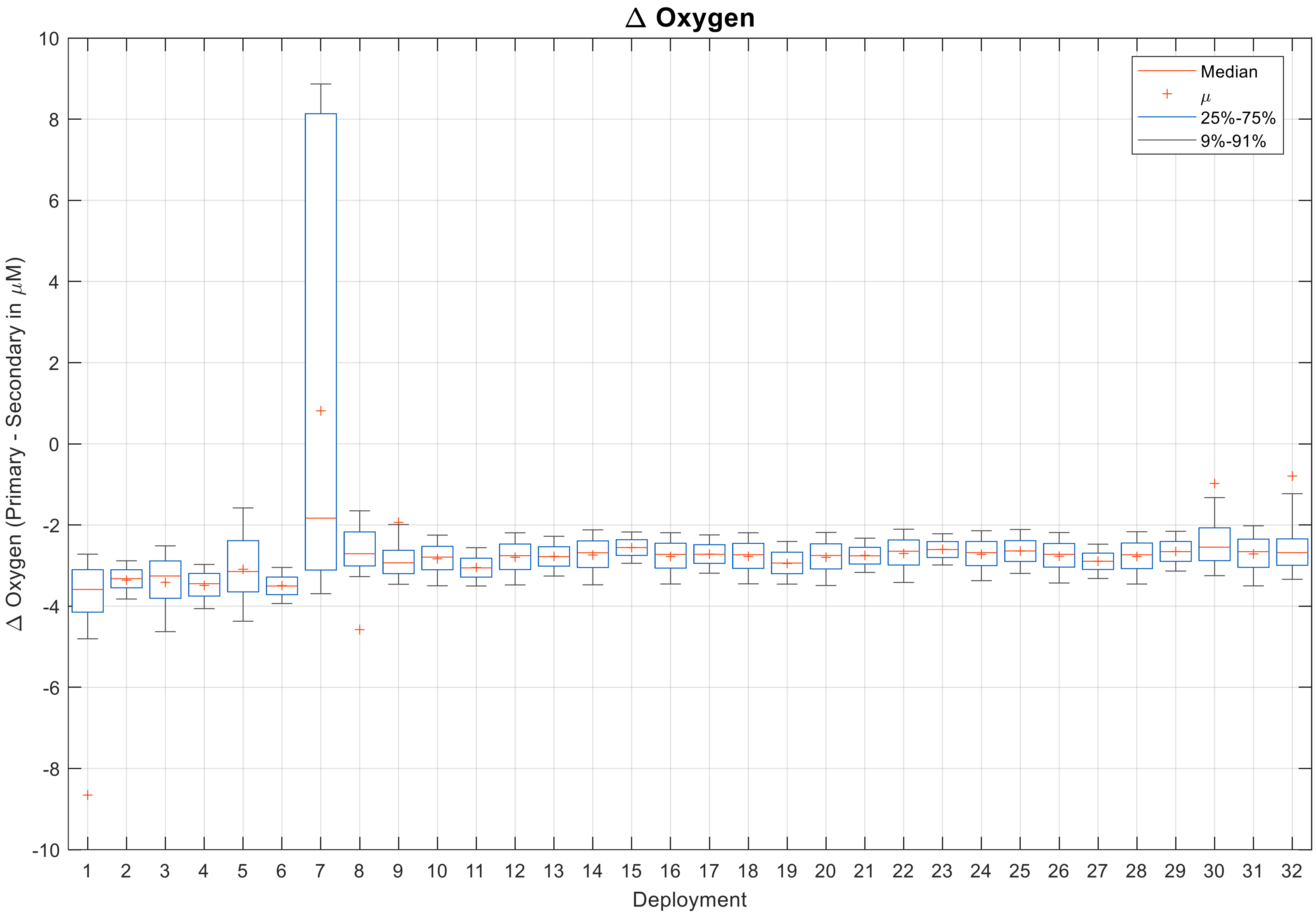

Figure 6 Box plots of the difference between primary and secondary dissolved oxygen sensors.

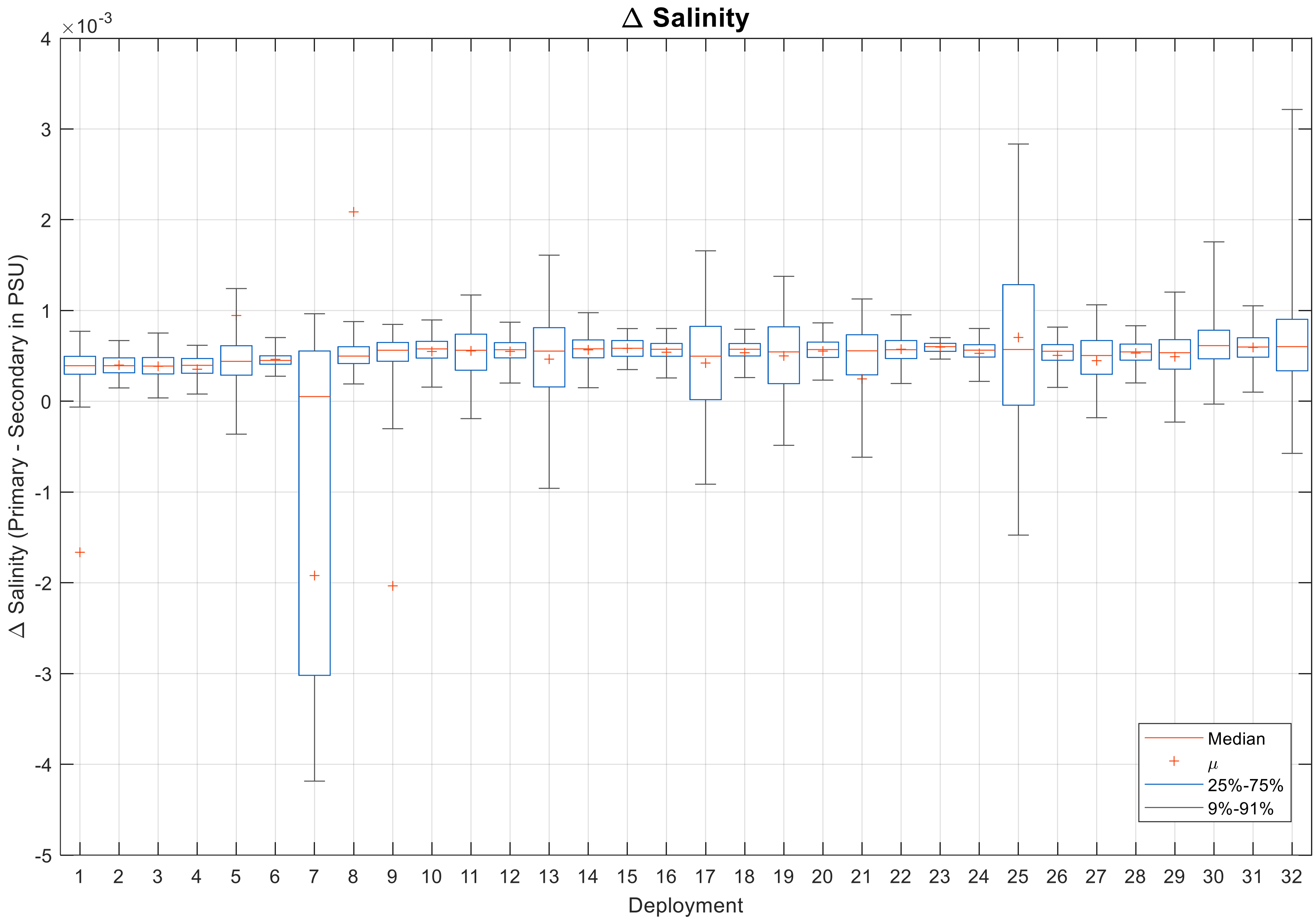

Figure 7 Box plots of the difference in calculated salinity (PSS-78) between primary and secondary sensors.

2.7 Triaxus Deployment Legs

Tow	Leg	Op. Number	Start time	End time	Start Latitude	Start Longitude	End Latitude	End Longitude
1	**1**	**1**	**2024-01-18T14:36:40Z**	**2024-01-18T16:33:52Z**	**65 24.504S**	**139 59.829E**	**65 15.773S**	**140 18.084E**
1	2	2	2024-01-18T16:34:31Z	2024-01-18T17:15:36Z	65 15.506S	140 18.587E	65 13.738S	140 13.680E
1	**3**	**3**	**2024-01-18T17:16:13Z**	**2024-01-18T19:02:46Z**	**65 13.887S**	**140 13.516E**	**65 26.839S**	**140 04.946E**
1	4	4	2024-01-18T19:03:03Z	2024-01-18T19:28:34Z	65 27.072S	140 04.780E	65 28.193S	140 06.124E
2	**1**	**5**	**2024-01-26T03:06:12Z**	**2024-01-26T07:18:14Z**	**64 00.244S**	**131 59.151E**	**64 27.409S**	**131 59.996E**
2	2	6	2024-01-26T07:18:51Z	2024-01-26T08:06:14Z	64 27.968S	131 59.993E	64 29.375S	132 05.166E
3	1	7	2024-02-04T12:47:00Z	2024-02-04T13:40:03Z	61 54.361S	113 21.281E	61 57.215S	113 25.834E
3	2	8	2024-02-04T14:01:21Z	2024-02-04T14:45:34Z	61 59.389S	113 29.140E	61 59.921S	113 34.904E
4	1	9	2024-02-13T12:29:34Z	2024-02-13T13:48:37Z	54 25.048S	114 59.094E	54 24.486S	114 49.943E
4	**2**	**10**	**2024-02-13T13:48:59Z**	**2024-02-13T14:45:32Z**	**54 24.304S**	**114 50.149E**	**54 18.132S**	**114 56.299E**
4	3	11	2024-02-13T14:45:54Z	2024-02-13T14:57:54Z	54 17.986S	114 56.447E	54 17.665S	114 58.685E
4	**4**	**12**	**2024-02-13T14:58:14Z**	**2024-02-13T15:58:02Z**	**54 17.703S**	**114 58.797E**	**54 21.396S**	**115 09.791E**
4	5	13	2024-02-13T15:58:23Z	2024-02-13T16:14:39Z	54 21.481S	115 10.047E	54 23.083S	115 11.177E
4	**6**	**14**	**2024-02-13T16:14:59Z**	**2024-02-13T17:14:14Z**	**54 23.147S**	**115 11.109E**	**54 29.533S**	**115 04.614E**
4	7	15	2024-02-13T17:15:04Z	2024-02-13T17:29:27Z	54 29.730S	115 04.415E	54 30.126S	115 01.872E
4	**8**	**16**	**2024-02-13T17:29:45Z**	**2024-02-13T18:31:36Z**	**54 30.084S**	**115 01.750E**	**54 26.289S**	**114 50.471E**
4	9	17	2024-02-13T18:32:17Z	2024-02-13T18:43:58Z	54 26.176S	114 50.148E	54 24.874S	114 49.605E
4	**10**	**18**	**2024-02-13T18:44:16Z**	**2024-02-13T19:43:22Z**	**54 24.810S**	**114 49.670E**	**54 18.433S**	**114 55.994E**
4	11	19	2024-02-13T19:43:41Z	2024-02-13T19:58:19Z	54 18.285S	114 56.140E	54 17.654S	114 58.653E
4	**12**	**20**	**2024-02-13T19:58:38Z**	**2024-02-13T21:02:43Z**	**54 17.690S**	**114 58.762E**	**54 21.693S**	**115 10.674E**
4	13	21	2024-02-13T21:03:42Z	2024-02-13T21:13:19Z	54 21.858S	115 11.011E	54 22.935S	115 11.307E
4	**14**	**22**	**2024-02-13T21:13:40Z**	**2024-02-13T22:17:16Z**	**54 22.999S**	**115 11.252E**	**54 29.577S**	**115 04.574E**
4	15	23	2024-02-13T22:17:34Z	2024-02-13T22:32:12Z	54 29.713S	115 04.433E	54 30.178S	115 02.030E
4	**16**	**24**	**2024-02-13T22:32:30Z**	**2024-02-13T23:34:29Z**	**54 30.137S**	**115 01.908E**	**54 26.395S**	**114 50.788E**
4	17	25	2024-02-13T23:34:54Z	2024-02-13T23:47:46Z	54 26.304S	114 50.526E	54 24.928S	114 49.556E
4	**18**	**26**	**2024-02-13T23:48:08Z**	**2024-02-14T00:50:18Z**	**54 24.851S**	**114 49.626E**	**54 18.148S**	**114 56.284E**
4	19	27	2024-02-14T00:50:37Z	2024-02-14T01:02:07Z	54 18.003S	114 56.426E	54 17.638S	114 58.579E
4	**20**	**28**	**2024-02-14T01:02:24Z**	**2024-02-14T02:08:27Z**	**54 17.666S**	**114 58.678E**	**54 21.713S**	**115 10.716E**
4	21	29	2024-02-14T02:09:03Z	2024-02-14T02:55:39Z	54 21.854S	115 10.997E	54 23.507S	115 05.572E
5	1	30	2024-02-14T17:57:16Z	2024-02-14T19:09:06Z	54 23.983S	114 59.506E	54 28.415S	114 58.922E
5	**2**	**31**	**2024-02-14T19:09:29Z**	**2024-02-14T21:02:44Z**	**54 28.389S**	**114 59.218E**	**54 20.302S**	**114 58.477E**
5	3	32	2024-02-14T21:03:07Z	2024-02-14T21:31:17Z	54 20.257S	114 58.950E	54 21.652S	115 00.277E

Table 5: CapPro deployment grouping. Legs with undulation data available in the final dataset are in bold.

CapPro deployments were grouped for each Triaxus deployment as shown in Table 5.

All legs have been processed and are included in the final dataset, except for legs noted below. The processed legs include deployment, recovery, and turn legs where no useful undulation data are present, as well as the undulation legs.

3 References

Foppert, A., & Rintoul, S. (2024). *The RV Investigator. Voyage Plan* IN2024_V01. Retrieved from Marine National Facility: Voyage Plans and summaries: https://mnf.csiro.au/en/Voyages/Voyage-Catalogue

Pender, L., & NCMI Information & Data Centre. (2022, September 1). *Data Quality Control Flags.* Retrieved March 28, 2023, from CSIRO NCMI Information and Data Centre - Data Trawler: https://www.marine.csiro.au/data/trawler/download.cfm?file_id=4716

4 Appendices

A.1 Glossary

CapPro – Internal CSIRO MATLAB-based CTD data processing software. Please see the contact information at the end of this report for more information.

Deployment – Relates to one instance of the Triaxus entering the water, being towed, then retrieved from the water.

Leg – A Section or concatenation of Sections that can be analysed as one data set. A Leg is equivalent to a Section, except in cases where there are multiple Sections created to restrict data file size along a single Leg of a Tow.

Operation number – A monotonically increasing index across the voyage, used internally during data processing.

Scan file – A file structure containing data collected from the deployment of the Triaxus-mounted CTD and auxiliary sensors.

Section – Part of a Tow delineated either by change in operation, such as undulation commencing or terminating or change of course, or to restrict data file size for convenience and disaster recovery.

Tow – A contiguous Triaxus operation intended to be treated as one data set.

For example, a Triaxus Tow might consist of 2 Deployments, where the vehicle was removed from the water for inspection during the Tow. During the first Deployment the vehicle was put in the water, towed on one course for 9 hours, then the course was changed, and then it was towed for a further 3 hours. The first 9-hour Leg was broken into 3 Sections of 3 hours each where data acquisition was restarted, and a new data file created between each Section. The Section while the course was changing, and the vehicle ceased undulating was recorded separately and processed as its own Leg.

A.2 NetCDF Variables

The following variables are available in the provided NetCDF files. Variables marked with a * have a corresponding quality control flag variable. QC Flags are described in Appendix A.3.

Variable name	Description	Units
pressure	Pressure at the CTD pressure sensor on the Triaxus	decibar
latitude	Estimated latitude of the Triaxus	decimal degrees North
longitude	Estimated longitude of the Triaxus	decimal degrees East
distance	Distance along the tow	km
waterDepth	Depth of water at the estimated position of the Triaxus	m
temperature *	Calibrated reading from the temperature sensor on the CTD sensor suite (i.e., primary or secondary) with the best T/C/DO data quality overall	°C
conductivity *	Calibrated reading from the conductivity sensor on the CTD sensor suite (i.e., primary or secondary) with the best T/C/DO data quality overall	S/m
salinity *	Calibrated salinity derived from the temperature and conductivity sensors on the CTD sensor suite (i.e., primary or secondary) with the best T/C/DO data quality overall	PSU
temperature_2 *	Calibrated reading from the temperature sensor on the CTD sensor suite (i.e., primary or secondary) with the second-best T/C/DO data quality overall	°C
conductivity_2 *	Calibrated reading from the conductivity sensor on the CTD sensor suite (i.e., primary or secondary) with the second-best T/C/DO data quality overall	S/m
salinity_2 *	Calibrated salinity derived from the temperature and conductivity sensors on the CTD sensor suite (i.e., primary or secondary) with the second-best T/C/DO data quality overall	PSU
oxygen *	Calibrated reading from the oxygen sensor on the CTD sensor suite (i.e., primary or secondary) with the best T/C/DO data quality overall	µmol/L
oxygen_2 *	Calibrated reading from the oxygen sensor on the CTD sensor suite (i.e., primary or secondary) with the second-best T/C/DO data quality overall	µmol/L
par *	Calibrated reading from the QCP-2300 Photosynthetically Active Radiation sensor	$\mu E/m^2/sec$
transmissometer *	Calibrated reading from the Wetlabs C-Star transmissometer	%
chlorophyll *	Calibrated reading for chlorophyll from the ECO Triplet	µg/L
obs *	Calibrated reading for optical backscatter from the ECO Triplet	m^{-1}
cdom *	Calibrated reading for coloured dissolved organic matter from the ECO Triplet	ppb
nitrate *	Uncalibrated reading from the SUNA sensor	µM (= µmol/L)
pitch *	Pitch of the Triaxus as recorded by the Triaxus flight data	degrees
roll *	Roll of the Triaxus as recorded by the Triaxus flight data	degrees
altimeter *	Altitude of the Triaxus above the seafloor	m
cablelength *	Cable length between the winch and Triaxus as recorded by the Triaxus flight data	m

Table 6: NetCDF data variables

A.3 Data Quality Control Flags

The information in this appendix is from (Pender & NCMI Information & Data Centre, 2022).

A.3.1 Specification

All quality control flags are to be unsigned integer numbers in the range 0 to 255. Where appropriate, the flags are to be stored as unsigned byte length values. Each byte length QC flag is subdivided into 3 fields. These fields are defined as follows:

Data State (bits 6 & 7)

The data state describes the overall status of the data without concern about the type of error, and the type of correction process performed on the data, if any. If the QC is unknown, the person loading data must determine the data state, i.e., unknown QC does not necessarily imply no QC.

Data State	Numeric value	Description
0	0	Data are good
1	64	Data are suspect
2	128	Data are bad
3	192	No QC

Operation type (bits 4 & 5)

The operation type describes the type of operation performed on the data to enable it to be classified with the given data state.

Operation	Numeric value	Description
0	0	No operation – data used as is.
1	16	Data have been interpolated to replace bad values.
2	32	Data have been averaged or otherwise filtered.
3	48	Data have been manually adjusted.

Error type (bits 0 – 3)

The error type describes the type of data error detected which resulted in the given data state and subsequent operation on the data.

Error type	Numeric value	Description
0	0	No error – data are good, or if no QC, error is unknown.
1	1	Hardware error.
2	2	Software error.
3	3	Operator error.
4	4	Error flagged by hardware.
5	5	Error flagged by processor.
6	6	Analytical error.
7	7	Recording anomaly, e.g., transcription error.

8	8	Data stream corrupted, e.g., communications fault
9	9	Data out of range.
10	10	Anomalous spike, e.g., data spikes.
11	11	Preliminary processing (calibration) only.
12	12	Unprocessed (uncalibrated) or processing error.
13	13	No data – data missing for unknown reason.
14	14	Timing error.
15	15	User defined – user must provide adequate description.

A.3.2 Numeric interpretation

The complete flag for a given data element is the sum of the numeric values of the 3 fields. To unpack a flag, the user can either use a lookup table, or perform the following manipulations:

Arithmetic method	Bit manipulation method
To unpack a flag: state = int(flag / 64) op = int((flag – state * 64) / 16) error = flag – state * 64 – op *16 **To pack a flag:** flag = state * 64 + op * 16 + error	**To unpack a flag:** state = flag >> 6 op = (flag & 0x30) >> 4 error = flag & 0x0f **To pack a flag:** flag = (state << 6) & (op << 4) & error

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, add 256.

If a user is only interested in the state flag, the following can be used to interpret flags:

State	Unsigned Byte	Signed Byte
Good	0 ≤ flag ≤ 63	0 ≤ flag ≤ 63
Suspect	64 ≤ flag ≤ 127	64 ≤ flag ≤ 127
Bad	128 ≤ flag ≤ 191	-128 ≤ flag ≤ -65
No QC	192 ≤ flag ≤ 255	-64 ≤ flag ≤ -1

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