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RV *Investigator* Triaxus Data Processing Report

Voyage ID	**IN2022_V06**
Voyage Title	Integrated Marine Observing System: Monitoring of East Australian Current property transports at 27 degrees South
Depart	Brisbane, 14 July 2022, 10:15 UTC
Return	Brisbane, 30 July 2022, 08:00 UTC
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Document History

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24 October 2023	1.1	Stephanie Petillo	Adding details
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20 February 2023	1.3	Stephanie Petillo	Adding tow location and statistics tables
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31 March 2023	1.5	Stephanie Petillo	Final data verification updates

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1 Summary

The main objective of this voyage was the recovery of six full-depth moorings from the abyssal waters off Brisbane, being used to monitor the East Australian Current (EAC), including associated CTD operations for mooring instrument calibration and surveying of the EAC by ADCP and Triaxus. Additional Triaxus, CTD, ADCP and sub-bottom profiler operations were undertaken to identify future coring sites for paleoclimate studies.

This report describes the production of quality controlled Triaxus data from RV *Investigator* voyage IN2022_V06.

5 Triaxus tows were conducted to study the spatiotemporal variability of water on the shelf near the Stradbroke Island National Reference Station (NRS), characterise shelf boundary exchanges, and sample eddies coming from the waters around Fraser Island. See the IN2022_V06 voyage plan for more details.

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). Additional MNF-supplied sensors included a Sea-Bird Scientific SUNA V2 nitrate sensor.

The Triaxus worked well overall. The LOPC failed on Tow 1 and in the last 30 minutes of Tow 2 but was repaired in each case and worked well for Tows 3 - 5. During processing of Tow 2 Leg 1 (deployment) and Tow 2 Leg 3 (recovery), no vertical casts were created due to insufficient pressure ranges and unmet interval requirements in the data. (This is not unexpected for non-undulation legs.) During processing of Tow 4 Leg 4, 'waterDepth' values were output as NaN in the processed Tow 4 Leg 4 data files due to large sections of water depth readings reported as NaN in the scan files from the end of Tow 4 Leg 3 through the beginning of Tow 4 Leg 4. The rest of the tows and legs processed normally.

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 NetCDF 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 (see Appendix A.1).

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

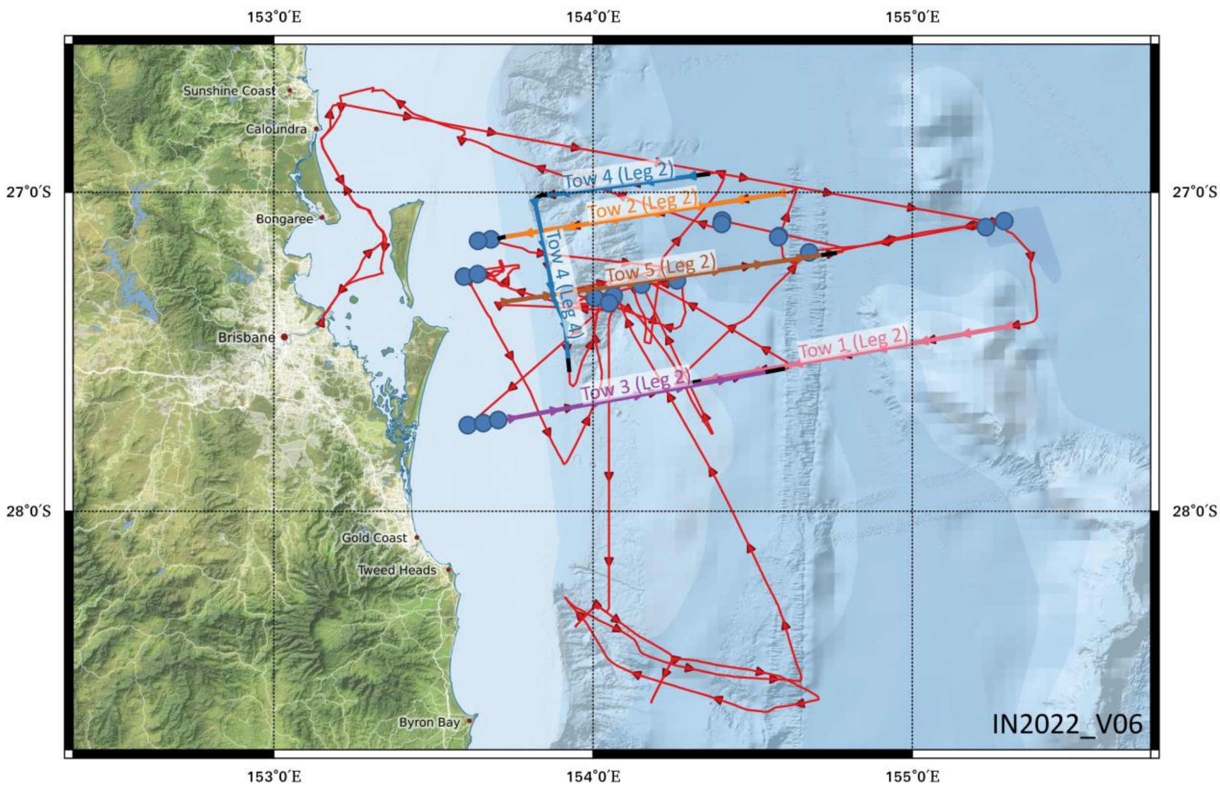

Figure 1: Voyage track (red) with Triaxus tows (non-red coloured lines) and CTD locations (blue dots)

2 Data Processing

2.1 Background Information

5 Triaxus tows were conducted, divided in the CTD acquisition software, Seasave, into 17 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: 002 (Serial Number S1511990)

Sensor Description	Data Channel	SBE9 Connector	Model	Serial Number
CTD			SBE9*plus* V2	1354 (#25)
Primary Temperature		JB1	SBE3*plus*	4522
Primary Conductivity		JB2	SBE4C	2312
Primary Pump		JB3	SBE5	9404
Secondary Temperature		JB4	SBE3*plus*	6285
Secondary Conductivity		JB5	SBE4C	3168
Secondary Pump		JB3	SBE5	8344
Primary Dissolved Oxygen	A0	JT2	SBE43	4167
Secondary Dissolved Oxygen	A1	JT2	SBE43	4184
PAR	A2	JT3	QCP2300HP	70111
Transmissometer	A3	JT3	CSTAR	2009DR
ECO Triplet	Payload 2 (12V)		FLBBCD2K	4049
Nitrate	Payload 3 (12V)		Satlantic SUNA V2	1891
Unused	Payload 4 (12V)			
LOPC	Payload 7 (12V)		Rolls Royce LOPC-1xT-3	11480
Iridium Beacon	-	-	Xeos Apollo 3	0132

Table 1: Triaxus sensor configuration on IN2022_V06

The raw CTD data were collected in SBE SeaSave version 7.26.4.0, converted to scientific units using SBE Data Processing version 7.26.4.0 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
  - Tow from offshore, towards the shelf.
- Leg 1 (Section 1)
  - Deployment

- Leg 2 (Section 2)
  - Undulations
- Leg 3 (Section 3)
  - Recovery

Tow 2

- Objective
  - Tow across the shelf, offshore to inshore.
- Leg 1 (Section 1)
  - Deployment
- Leg 2 (Section 2)
  - Undulations
- Leg 3 (Section 3)
  - Recovery

Tow 3

- Objective
  - Tow from inshore to offshore, overlapping the end with the end of Tow 1.
- Leg 1 (Section 1)
  - Deployment
- Leg 2 (Section 2)
  - Undulations
- Leg 3 (Section 3)
  - Recovery

Tow 4

- Objective
  - Tow from offshore to the inshore edge of the shelf break (Leg 2), then turn south (Leg 3) to tow along the inshore edge of the shelf break (Leg 4).
- Leg 1 (Section 1)
  - Deployment
- Leg 2 (Section 2)
  - Undulations
- Leg 3 (Section 3)
  - Turn
- Leg 4 (Section 4)
  - Undulations
- Leg 5 (Section 5)
  - Recovery

Tow 5

- Objective
  - Tow across the shelf, inshore to offshore.
- Leg 1 (Section 1)
  - Deployment
- Leg 2 (Section 2)
  - Undulations
- Leg 3 (Section 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.

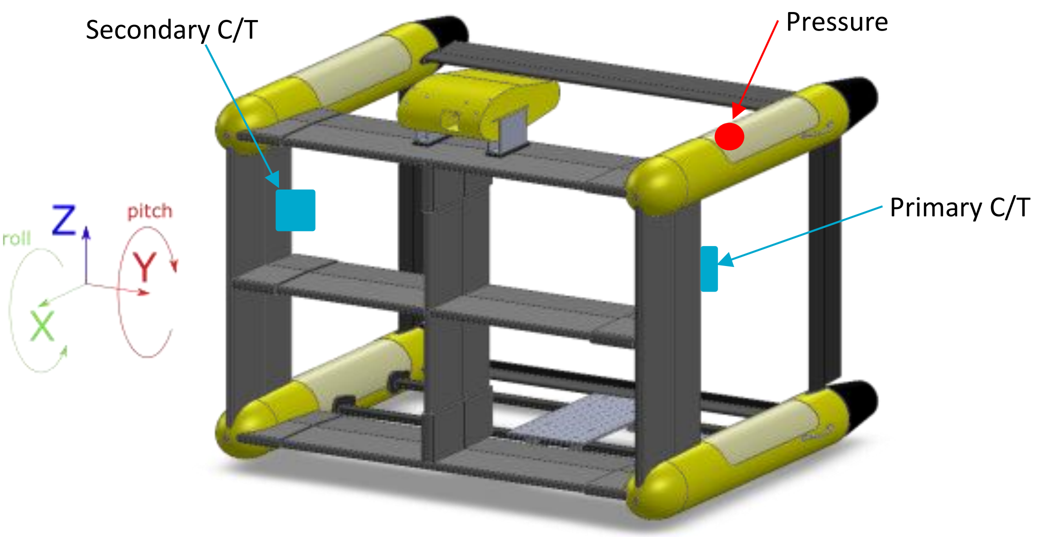

Figure 2: Triaxus General Arrangement. Pressure and C/T sensor locations approximate.

The pressure sensor location correction was *not* 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 $\mu E/m^2/s$. 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, though no usable data were collected on Tow1 and for the last 30 minutes of Tow 2 due to failures that were resolved prior to subsequent 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	-10	10000	0.8
Temperature	°C	-4	40	0.01
Conductivity	S/m	-0.01	10	0.01

Dissolved Oxygen	µmol/L	-0.1	500	1.5
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.

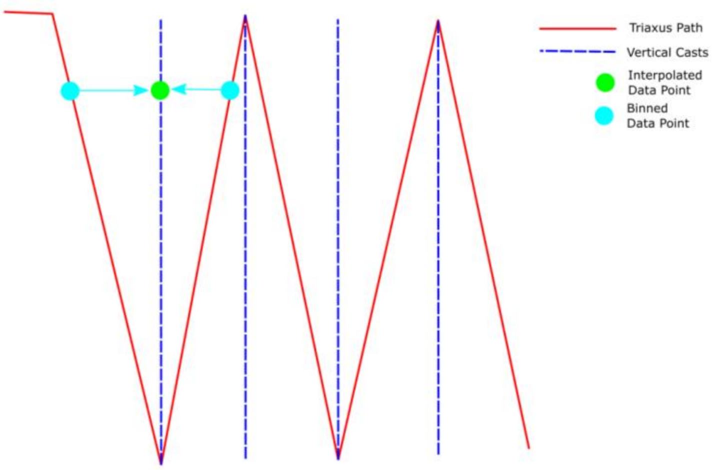

Figure 3: Vertical cast creation

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

Generally, the Triaxus data were of high quality, though there were a few issues encountered that affected various data products for certain tows:

- The LOPC failed on the Tow 1 resulting with no usable LOPC data for the tow. This was due to a cable issue that was subsequently fixed.
- During Tow 2, the LOPC worked until it cut out for the last 30 minutes due to an issue with an unused bulkhead. This resulted in missing LOPC data for those last 30 minutes. The instrument worked well on subsequent tows.
- At one point in the middle of Tow 3 the Triaxus inflected an undulation at 300 m instead of the pre-set 350 m maximum tow depth, so the tow was reset. There will be a short profile in the data that stops at 300 m.
- In the first hour of Tow 4 the Triaxus software crashed, and the system was quickly rebooted. There may be a small gap in data due to this.

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 throughout the deployments.

		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	2	0.00201	0.01014	2.24917	0.05928	0.01887	7.40869
2	2	0.00241	0.01159	1.9185	0.09242	0.03271	6.0564
3	2	0.00294	0.01305	2.15584	0.10708	0.03074	8.41889
4	2	0.00269	0.01309	1.62701	0.05546	0.02555	5.03477
4	4	0.00321	0.01316	1.5316	0.07677	0.02335	9.57083
5	2	0.00286	0.01228	1.75226	0.13675	0.03012	7.76144

Table 4: Mean and maximum absolute difference between primary and secondary CTD sensors

2.7 Triaxus Deployment Legs

Tow	Leg	Operation Number	Start time	End time	Start Latitude	Start Longitude	End Latitude	End Longitude
1	1	11	2022-07-16T07:39:33Z	2022-07-16T08:03:39Z	27°24.876'S	155°20.201'E	27°25.264'S	155°17.614'E
1	**2**	**12**	**2022-07-16T08:04:34Z**	**2022-07-16T15:58:08Z**	**27°25.295'S**	**155°17.446'E**	**27°35.578'S**	**154°19.738'E**
1	3	13	2022-07-16T15:58:34Z	2022-07-16T16:32:10Z	27°35.747'S	154°18.785'E	27°36.099'S	154°16.818'E
2	1	21	2022-07-17T07:58:06Z	2022-07-17T08:25:55Z	26°59.544'S	154°37.766'E	27°00.248'S	154°35.020'E
2	**2**	**22**	**2022-07-17T08:26:46Z**	**2022-07-17T15:05:41Z**	**27°00.274'S**	**154°34.854'E**	**27°08.330'S**	**153°43.641'E**
2	3	23	2022-07-17T15:06:22Z	2022-07-17T15:25:08Z	27°08.475'S	153°42.832'E	27°09.039'S	153°41.707'E
3	1	31	2022-07-24T08:11:10Z	2022-07-24T08:23:10Z	27°42.789'S	153°43.916'E	27°42.463'S	153°44.960'E
3	**2**	**32**	**2022-07-24T08:23:31Z**	**2022-07-24T15:24:21Z**	**27°42.446'S**	**153°45.016'E**	**27°33.538'S**	**154°33.877'E**
3	3	33	2022-07-24T15:24:44Z	2022-07-24T15:53:27Z	27°33.449'S	154°34.427'E	27°33.142'S	154°36.073'E
4	1	41	2022-07-25T07:48:43Z	2022-07-25T08:24:50Z	26°56.486'S	154°21.839'E	26°57.022'S	154°17.899'E
4	**2**	**42**	**2022-07-25T08:25:21Z**	**2022-07-25T12:10:53Z**	**26°57.042'S**	**154°17.750'E**	**27°00.713'S**	**153°50.268'E**
4	3	43	2022-07-25T12:12:09Z	2022-07-25T12:28:52Z	27°00.864'S	153°49.647'E	27°02.788'S	153°49.283'E
4	**4**	**44**	**2022-07-25T12:29:23Z**	**2022-07-25T16:05:37Z**	**27°02.912'S**	**153°49.310'E**	**27°31.990'S**	**153°55.376'E**
4	5	45	2022-07-25T16:06:05Z	2022-07-25T16:40:30Z	27°32.533'S	153°55.436'E	27°35.142'S	153°55.616'E
5	1	51	2022-07-26T10:45:29Z	2022-07-26T11:00:25Z	27°20.769'S	153°42.270'E	27°20.546'S	153°43.773'E
5	**2**	**52**	**2022-07-26T11:00:50Z**	**2022-07-26T20:27:56Z**	**27°20.544'S**	**153°43.878'E**	**27°11.687'S**	**154°43.726'E**
5	3	53	2022-07-26T20:31:25Z	2022-07-26T21:05:07Z	27°11.537'S	154°44.698'E	27°11.308'S	154°46.273'E

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, with the exception of certain 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.

Legs with data processing issues:

- Tow 2, Leg 1 (Deployment) – No vertical casts (*AvgCast.mat file) created due to monotonic pressure or pressure range too small

- Tow 2, Leg 3 (Recovery) – No vertical casts (*AvgCast.mat file) created due to unmet interval requirements
- Tow 4, Leg 3 (Turn) – Depth data are partially missing from the end of the scan file for this leg (in2022_v06_04_003Ctd.nc)
- Tow 4, Leg 4 (Undulations) – Depth data are partially missing from the beginning and middle of the scan file for this leg (in2022_v06_04_004Ctd.nc), resulting in 'waterDepth' values of NaN in this leg's processed data files produced by CapPro (Tow4Leg4Avg.nc and Tow4Leg4AvgCast.nc)

3 References

Chapman, C. (2022). *RV Investigator Voyage Plan (*IN2022_V06*).* Retrieved from Marine National Facility: Browse all voyages: 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	µE/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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