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Australian XBT Quality Control Cookbook

Version 2.1

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Foreword

Expendable Bathythermographs (XBTs) have been used for many years by oceanographers to measure the temperature of the upper ocean. These instruments are simple devices which are designed to be deployed from moving vessels, enabling the use of ships of opportunity to collect data in repeated transects. The XBT has accordingly played an important role in several large international research programs, and the global data archives reflect this. Quality Control (QC) procedures are described for data recorded by XBTs. Examples are shown and described for commonly observed oceanographic features and instrument malfunctions. A QC system is described, which aids in the process of future validation and documentation of real features, and in the elimination of erroneous temperature profiles. There are some modes of malfunction of the XBT which appear very similar to real oceanographic features. This manual enables the user to better distinguish between the two. A knowledge of the different types of real and erroneous features, when combined with a local knowledge of water mass structure, statistics of data anomalies, the depth and gradient of the thermocline, and cross validation with climatological data in a statistical sense, ensures a data set of the best possible quality.

This document is an update to the original 'Quality Control Cookbook for XBT Data' Version 1.1 (Bailey et al, 1994). Over time, the QC routines used by the Australian team have developed and many codes have become redundant due to improvements in the recording systems and our understanding of failure modes. The older, redundant codes are now summarised in the Section 4.8 and the Appendices A to C. We urge the reader to refer to Bailey et al (1994) for more detail on these historical codes.

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Tables

Figures

Version control information

Version	Date	Change information	Author
1.0	1994	Original document	Bailey et al
2.0	October, 2022	Using Bailey et al (1994) as starting point: • Include all Australian Agencies • Move older codes to appendix and expand list of codes used historically • Change CSA philosophy to retain surface temperatures • Change GTSPP flags for interpolated or filtered data from flag 2 to flag 5 (changed) • Improve QC code descriptions and combine some codes into one • Separate flags into GTSPP quality level and QC codes • Update figures	Rebecca Cowley, Lisa Krummel
2.1	August, 2023	Fix error in flag for temperature for DOA in summary table 3. Flag 2 is corrected to flag 5. Update table 4 for HBR. Depth flag is corrected from flag 1 to flag 3. Update table 4 for CTR, depth flag is corrected from 1 to flag 3.	Rebecca Cowley

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Data was sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

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1 Introduction

The Quality Control (QC) procedures described here have been developed by participants in the Australian XBT Ship of Opportunity Program (including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian Bureau of Meteorology (BoM) and Royal Australian Navy (RAN)), specifically to assure the research quality of expendable bathythermograph (XBT) data at the delayed mode stage. This document is a new release of that of Baily et al (1994) with updates and historical information retained in Appendices A to C. For helpful information on operational XBT data collection best practices for quality assurance, the reader is referred to Parks et al (2022).

This manual provides an overview of real oceanographic features and instrument errors that have been monitored over a period of years and from which the Australian QC coding procedures have been developed. An example of each code is provided to illustrate the subtle differences in structure that occur when either an error or feature is recorded in the XBT profile data. Checking XBT data for the occurrence of these errors and features, combined with comparisons to climatological data and to neighbouring profile data, forms the basis of scientific quality control.

The ability to judge whether a feature is realistic for a particular region cannot easily be passed on to a QC operator from a manual such as this. Local knowledge of water mass structure, statistics of data anomalies, the depth and gradient of the thermocline, as well as climatological data must be incorporated into the validation process. These ingredients all help to establish if the specific event (e.g., an inversion) identified in the profile is probable or not for the region in which it was observed.

Types of malfunction of the XBT instrument must also be kept in mind when performing scientific QC. The QC operator should proceed with caution whilst ensuring that no good data is thrown away. This manual is intended to make the identification of real and erroneous features easier. It must be kept in mind, however, that the ability to make valid scientific QC decisions requires training and experience.

These procedures are designed to be applied to full resolution (every ~0.6 m in depth) data but can be applied to low to medium resolution, inflection point XBT data. However, the lower resolution makes it more difficult to identify some of the structures and failures described here.

2 Temperature Structure in the Oceans

The vertical temperature structure in the ocean is generally divided into three zones. There is an upper mixed layer with fairly uniform temperatures similar to those at the sea surface. The thermocline is the zone below the mixed layer in which the temperature gradient (rate of change of temperature with depth) is at a maximum. Below the thermocline is a deep zone in which temperature changes slowly. The depths of these features vary with time and geographic location. Some typical XBT profiles are depicted in Figure 1.

Sea surface temperatures in the open ocean generally vary between a maximum of 30°C near the equator to a minimum of -1.9°C (freezing temperature of seawater) at high latitudes. The temperature at the sea surface is often representative of the temperature over a range of depths that are well mixed by wind and wave action. Heat is transferred downwards to the deeper layers by the action of turbulence. A high degree of vertical uniformity with little variation in temperature, salinity, or density is therefore often observed in the upper layer.

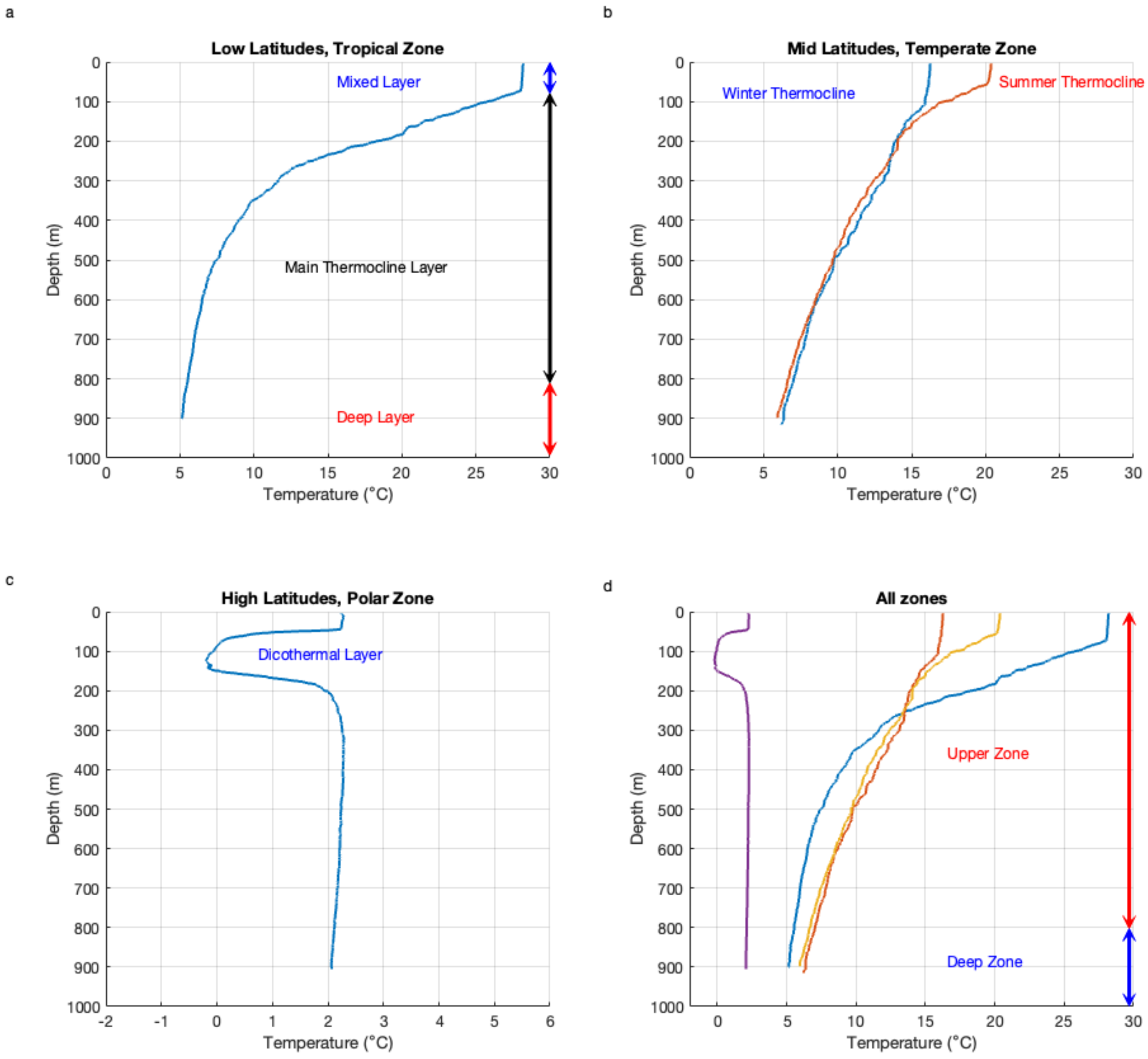
The surface mixed layer exhibits characteristic seasonal (especially in the mid and high latitudes) and regional variations in response to the local climatic conditions; and the depth of the mixed layer varies accordingly. During winter the mixed layer depth is enhanced by cooling from the surface and by strong wind and wave action. During summer, the winds are generally lighter, and the mixed layer does not usually extend as far. Generally, the mixed layer is between 50-100 m thick in low latitudes and 25-250 m (extending to the permanent thermocline) in mid latitudes. In high latitudes a near constant temperature profile can sometimes be observed over hundreds of metres depth.

Seasonal effects are limited to a narrow range of depths in the ocean by the extent of vertical mixing. A ‘seasonal’ thermocline may develop in some regions (mid and high-latitudes) from the surface to about 200 m depth in response to heating by the atmosphere. Summer warming accentuates the thermocline by diminishing the density of the surface layers, while winter cooling erodes the thermocline and establishes the mixed layer. The depth range from below the seasonal thermocline to about 1000 m is known as the ‘permanent’ or oceanic thermocline. This is the transition zone from the warm waters of the surface layer to the cold waters in the deep ocean. The ‘permanent’ thermocline is consistently present extending from 100-1000 m depth at low latitudes and from 200-1000 m at mid latitudes. However, no permanent thermocline is established at high latitudes (polar regions).

Although the temperature in the upper zone shows seasonal and regional variations in response to the local climatic conditions, the deep zone remains fairly constant in both these respects with a well-defined temperature-salinity relationship. Most types of XBT are designed to measure the vertical temperature structure in the top 450 m to 750 m of the water column so they do not generally extend far into the deep zone.

Apart from the mixed layer and thermocline, many other subtle changes in the ocean's vertical temperature structure may also be observed in an XBT temperature profile by a trained observer. Different types of fine structure associated with intrusions, convection or turbulent mixing events, on vertical scales of tens of centimetres to hundreds of meters, can often be picked up in an XBT profile, or series of profiles. Temperature inversions are often observed as an increase of temperature with depth in a profile and occur in regions of the ocean in which the local conditions favour their formation (e.g. inversions in the mixed layer are sometimes observed in the tropics). Other meso-scale ocean features such as eddies, fronts or convergence zones, may be pin-pointed by large temperature differences over a large depth range from one profile to another.

Figure 1. Typical mean temperature/depth XBT profiles for the open ocean. Adapted from Pickard and Emery, 1990



3 Overview of Quality Control Procedures

The Australian XBT Quality Control process uses a visual approach combined with an interactive editor to check and flag the data. The metadata is tested for correct time, position and other operator errors. Then temperature profiles are inspected for common malfunctions, regional oceanographic features, drop to drop consistency along the cruise track, and repeat drops of unusual features. Figure 2 shows the steps involved in the Australian quality control process.

3.1 Metadata assessment

The metadata is assessed first. It is vital that metadata such as date/time/location, probe and recorder types are recorded correctly and kept with the data. Incorrect metadata impacts on the final useability of the data – for example, an incorrect record of probe type will lead to miscalculation of depth and long-term ocean heat calculations (Cheng et al, 2016).

Errors detected in the time and position fields are corrected if possible; however, if these cannot be resolved with a reasonably high degree of confidence the temperature data is flagged bad as it cannot be properly referenced. The original position of XBTs deployed during a voyage are best viewed in the form of a mapped track plot while individual profile plots are examined. A check of unrealistic positions can be automatically performed using calculation of vessel speed from profile times, and the operator can be alerted if the ship speed is greater than 25 knots as most ships (with some exceptions) do not travel faster than 25 knots.

Test probes are built with precision resistors and allow simulation of a real XBT probe. Test probe information is checked to ensure the integrity of the recording equipment. Test probes should show less than 0.005 °C in temperature variation throughout a test (Turo Technology, 2015). Multiple failures in test probes can indicate poor earthing or other system errors that can manifest in large or subtle errors in profiles (for example, total failure to collect temperature data through to spikes and high-frequency noise in the profile).

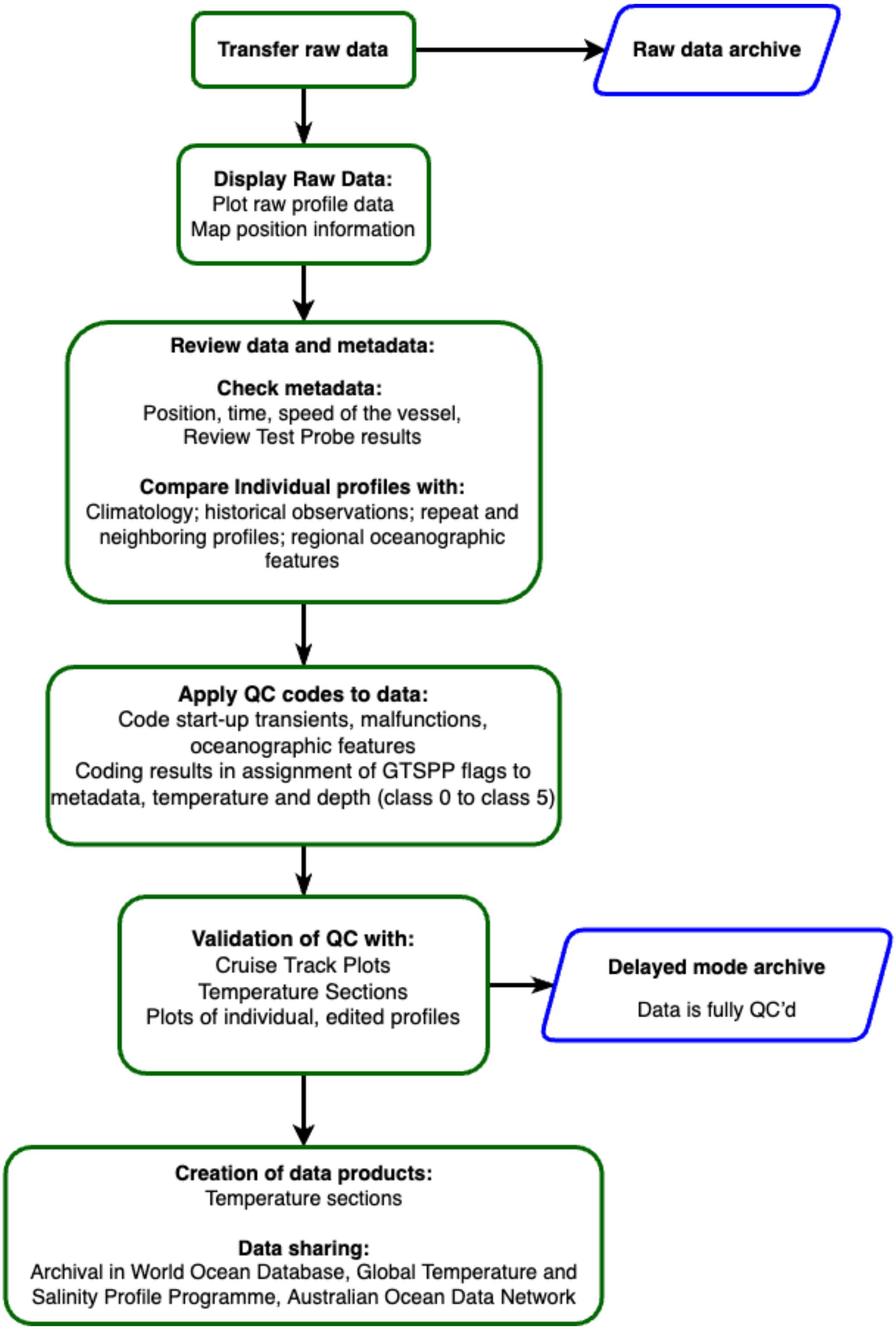
3.2 Temperature Profile assessment

Once the metadata has been validated, the individual profile plots are inspected for common malfunctions, regional oceanographic features and profile to profile consistency. Unusual features are cross validated by comparison with:

1. Repeat (within 15 minutes) or neighbouring profiles from the same voyage;
2. Comparison to climatology products;
3. Comparison to an archive of temperature profiles recorded in the region (eg, XBT, CTD, Argo).

Features (such as temperature inversions) and failures (for example, wire stretches) can appear and be flagged at any point in the profile. If anomalous features are present, the operator should always look at a repeat or neighbouring drops for confirmation and if these are not available, review against climatology and archived/historical temperature profiles in the region. Climatologies in use in Australia include Levitus, (1982), the CSIRO Atlas of Regional Seas (CARS) (Ridgway et al, 2002) and an Argo-based climatology that has been constructed at CSIRO for internal use.

Figure 2. Australian XBT Quality Control Process from raw to delayed-mode data



4 Application of Scientific Quality Control to XBT data

When an XBT probe is launched, the data recording cycle is triggered by contact of the sea electrode with the sea surface. Data recording continues until the wire breaks or the recording is terminated by the operator. As the probe descends through the water column, insulated copper wire is unreeled simultaneously from the probe spool and from the canister spool connected to the XBT launcher. This wire provides a sensor line from the probe to the computer on board the vessel. Temperature changes in the surrounding water, measured as change in electrical resistance, are generally recorded in the bridge circuit at a rate of 10 Hz (~65 cm depth intervals) and a resolution of ± 0.01°C. The water depth is not sensed directly by the probe but calculated from the time elapsed since probe contact with the water and the probe's expected fall rate. The XBT probe accuracy is rated to ± 0.10°C so that noise of this order or smaller can usually be ignored.

Many types of malfunctions can cause erroneous temperature readings in the temperature profile. The faults may be restricted to a spike in a single recorded temperature value or may affect the temperature over a range of depths. The errors may have a high wave-number/jittery appearance or may be smooth features over tens of metres. Some of these malfunctions produce temperature errors that resemble real features such as temperature inversions or fronts. Many of the profiles can be "cleaned up" by deleting or filtering a portion of the original data.

Many types of flagging schema are available to apply quality indicators to oceanographic data. The application of quality flags to Australian XBT data, and indeed, to all XBT data collected under the GOOS (Global Ocean Observing System) SOOP (Ship of Opportunity) programs, follows the GTSPP (Global Temperature and Salinity Profile Program) flagging scheme (Table 1) (https://www.ncei.noaa.gov/products/global-temperature-and-salinity-profile-programme). In the Australian XBT QC process, GTSPP flags are used to indicate the quality of each and every temperature and depth data point. To determine what quality to apply to the data, we have defined quality codes. This manual is organised by quality code and will ensure the correct GTSPP flags are applied. In the XBT data files, each code is recorded similarly to the secondary flag described in IOC (2013). The QC code is stored separately with a record of the depth at which the code is applied.

We use shortened codes throughout this document. These codes were useful historically where space in data files was at a premium. They are also useful in any Graphical User Interface (GUI) used as a QC tool, as seen in the figures throughout the document. In some data files (eg, GTSPP ascii files), the codes are used, in others (eg, netCDF), the full code label may be included. Examples of how QC codes and GTSPP flags are stored in netCDF and ascii formats are given in Appendix F.

Since there are real oceanographic features and XBT malfunctions which may appear very similar to each other, a decision must be made about which QC code to apply. Each code indicates what level of GTSPP flag to apply to the metadata, temperature and/or depth data. There are two general types of GTSPP flag that can be applied: **Accept** flags (green in Table 1) and **Reject** flags (red in Table 1).

Philosophy of GTSPP quality flag application to XBT data

XBT raw data are recorded as temperature and time, with depth calculated from a probe-dependent fall rate equation using fixed coefficients and time. The temperature data are measured from the surface down and delayed-mode QC should be undertaken in a top-down manner. Usually, faults that occur at a given depth impact on all deeper temperature data, therefore, all data below a fault will have the same GTSPP flag applied.

Data quality flags should only ever be applied in increasing numerical value (decreasing quality) with descending depth. For example, GTSPP quality flag 1 should not appear below (deeper) than flags 2, 3 or 4. There are two exceptions:

1. Start-up transients (CS) which have a GTSPP flag of 3 applied.
2. Any code where flag 5 is applied to replaced data (for example EI and HF).

A profile may have multiple QC codes applied, therefore the GTSPP quality flags can change throughout the profile from the surface to the deepest point. The quality may stay the same, or downgrade at the depth of application of a QC code.

If in doubt about applying an Accept or Reject flag to the profile, the QC operator should take a conservative approach and use the lower quality flag.

Low depth-resolution data including inflection point data and BATHY messages, must be quality controlled with a certain amount of caution as identification of malfunctions and features is difficult with limited temperature-depth data.

In this document, the quality codes are grouped according to the following categories:

- Profile Metadata QC
- Recorder QC
- Profile Data QC
- Inversion and wire stretch QC
- Structure and signal leakage QC
- Oceanic Features QC

The detailed explanation of the scientific QC codes is the subject of the remainder of this manual and should help facilitate and standardise the process of scientific quality control. The codes have been designed to be used as a research tool as well as quality control indicators, such that when the occurrences of codes are mapped, we can build an understanding of regional variations in features of interest. This can then be used to better determine whether an apparent feature is scientifically probable for a certain area.

Table 1. GTSPP quality flags. Green cells indicate Accept flags and red cells Reject flags.

Flag	Quality	Description	Comment
0	No QC	No quality control has been performed on this element.	Data have not yet been assessed.
1	Good data	The data is good, all features are confirmed.	Flag 1 data are high quality data in which no malfunctions have been identified and all real features have been verified.
2	"Probably" good data	The element appears to be probably good.	Flag 2 data are good data in which some features (probably real) are present but these are unconfirmed. Minor malfunctions may be present but these errors are small and/or can be successfully corrected without seriously affecting the overall quality of the data.
3	"Probably" bad data	The element appears doubtful.	Flag 3 data are suspect data in which unusual, and probably erroneous features are observed. Data remain potentially correctable.
4	Bad data	The element appears erroneous.	Flag 4 data are those in which obviously erroneous values are observed and there is no likelihood of correction.
5	Changed	The element has been changed.	Flag 5 data have been altered, with original values (before the change) preserved in the raw data. For example when data has been interpolated to correct a spike.
6 - 8	Reserved	Reserved for future use.	Flag 6 - 8 are reserved for future use.
9	Element missing	The element is missing.	Flag 9 data indicate that the element is missing.

4.1 Example of typical application of QC codes

A Graphical User Interface (GUI) is best used when undertaking scientific/visual QC of XBT data. In Australia, various tools have been used over time, early ones written in Fortran ('Quest') and later ones in Matlab ('MQuest') and Python ('PyQuest') coding. All have had similar features and the method of application of QC codes using any of these GUIs remains constant.

Features of the GUI include:

1. Ability to import the raw files recorded by the recording device (eg, Turo Quoll or Sippican MK21) into the GUI. Also, to export the QC'd files to various formats.
2. The main screen showing a map of profile locations, a list of profile metadata, a 'waterfall' plot of the profiles, a temperature-depth plot and numerical list of the first profile collected.
3. The ability to move forward and backward in order of the time of profile collection, at the same time, the map and all associated plots will update.
4. The temperature-depth profile plot includes a 3x standard deviation window from the climatology database specific to the location of the profile. The user can switch view to show neighbouring profiles (collected from the same voyage before and after the current profile) and profiles within a distance defined by the user.
5. The operator can choose to include historical data (eg, XBT, Argo, CTD) for plotting. This allows the comparison with historical data collected in the same region.
6. The GUI allows the use of shortcut keys to quickly apply codes and GTSPP flags without excessive mouse clicks. Alternatively, some codes could be applied automatically on import (eg, wire break).

The QC operator will learn the best way to apply the codes after many hours of QC. Below is an example of the process followed to QC a typical SOOP XBT profile. The codes can be applied in different sequences based on the profile quality.

1. Apply Quality Control Check (QC) code. This indicates that scientific QC has been done for this profile.
2. If the profile is a Test Probe (TP) or a Duplicate (DU), apply TP or DU and move to the next profile. No other codes are necessary.
3. Check for Depth Offsets (DO), which occur rarely and are easy to identify. If a depth offset has occurred, the DO code should be applied before all others.
4. Apply Surface Transient (CS) code if the profile has not failed at the surface or within 3.6 m.
5. Apply Wire Break (WB) code if wire breaks are present.
6. Apply Hit Bottom (HB) and optionally No Good (NG) code for probes that hit the bottom.
7. Apply Repeat Profile (RE) code if the automatic speed check indicates the profile was collected within 15 minutes of a neighbouring profile.
8. Compare the current profile with the profiles collected immediately before and after. Review the lower (>500m) temperatures of the profile – if the current profile deviates from the neighbouring profiles, check for Leakage (LE), Electrical Interference (EI) and Wire Stretch (WS).
9. Check for significant offsets in temperatures from neighbouring profiles and climatology. Offsets in temperature of the entire profile may be indicative of a date/time (TE) or position

(PE) error (review on the map). A speed check run automatically by the GUI will also highlight errors in date/time and position records. Other reasons for acceptable significant offsets could be Eddy Fronts (EF) or Temperature Offsets (TO, flag 2). Reasons to reject temperature offsets should also be considered (eg, LE, EI, High Frequency noise (HF), Constant Temperature (CT), WS, TO (flag 3)).

10. Check for Spikes (SP), Electrical Interference (EI), High Frequency noise (HF) and Leakage (LE) failures throughout the profile.
11. Finally, check for temperature Inversions (IV) and Eddy Fronts (EF) by reviewing one to two neighbouring profiles collected before and after the current profile.

4.2 Profile metadata QC

The QC codes in the profile metadata category (Table 2) are concerned with the correctness of the time, position and probe type identifier fields in addition to identifying duplicates and repeat profiles and that expert visual QC has been completed.

The GTSPP flags can be applied to the profile metadata, all temperature data in a profile and all depth data in a profile as indicated in the following sections.

Table 2. Summary of Profile Metadata QC codes.

QC code label	Code	Use Description	GTSPP flag		
			Metadata	Temperature	Depth
Quality Control Check	QC Accept	Indicates that manual, scientific Quality Control has been performed on a profile and data has been reviewed by a quality control operator	None	1 from the surface	1 from the surface
Repeat Profile	RE	Indicates a repeat profile, data collected within 15 minutes of another profile	None	None	None
Duplicate Profile	DU Reject	Where two or more profiles are exact copies, retain one and all copies are rejected.	None	4 from the surface	1 from the surface
Position Error	PE Accept	Position is correctable, manually correct latitude and/or longitude information.	5 for latitude and/or longitude	2 from the surface	1 from the surface

QC code label	Code	Use Description	GTSPP flag		
			Metadata	Temperature	Depth
	PE Reject	Latitude and/or longitude are incorrect and a correction cannot be determined, retain position information.	3 for latitude and/or longitude	3 from the surface	1 from the surface
Time Error	TE Accept	Date/time information is correctable, manually correct time or date information.	5 for date/time	2 from the surface	1 from the surface
	TE Reject	Date/time information cannot be corrected, retain original date/time information.	3 for date/time	3 from the surface	1 from the surface
Probe type error	PR Accept	Probe type erroneous and can be corrected, depth and temperature are values recalculated.	5	5 from the surface	5 from the surface
	PR Reject	Probe type erroneous, but correction is unable to be performed. Retain original probe type and temperature/depth values.	3	3 from the surface	3 from the surface

4.2.1 Scientific Quality Control Check Completed (QC)

The scientific quality control check code is applied by the QC operator to indicate that a profile has been scientifically (or visually) quality controlled. All temperature and depth data are flagged with GTSPP flag 1.

Code	**Depth of application**	**GTSPP Quality flag**		
		Metadata	**Temperature**	**Depth**
QC Accept	Surface	1	1	1

4.2.2 Repeat Profile (RE)

A repeat profile is defined as an XBT deployed within 15 minutes of another. A field officer may choose to repeat a drop because of:

- Suspected probe malfunction on a previous drop
- A desire to confirm a suspected real feature (eg, a temperature inversion)
- High density sampling for a particular scientific reason (eg, probe fall rate tests)

Identification of repeat profiles can be automated and the QC operator alerted via the GUI. The RE code is applied at the surface of the original profile and the surface of all repeat drops.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
RE	Surface of original and all repeat profiles	None	None	None

4.2.3 Duplicate Drop (DU)

A duplicate drop is an exact copy of an XBT profile that is already in the database. This may occur when raw data is imported more than once for quality control. Duplicate profiles should have GTSPP flag 4 applied to all temperature values. These profiles are not exported to or included in delayed-mode archives.

Identification of duplicate profiles can be automated and the QC operator alerted via the GUI.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
DU Reject	Surface	None	4	1

4.2.4 Position Error (PE)

A position error is an error in a position field (latitude or longitude) which has been identified by the QC operator, from log sheets, or from an automated speed check (ship speed of greater than 25 knots). The latitude and/or longitude field(s) may be replaced if the correct location is known, or retained if a corrected location cannot be determined.

Position errors can have either Accept or Reject GTSPP flags applied.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
PE Accept	Surface	5 to corrected latitude and/or longitude	2	1
PE Reject	Surface	3 to original latitude and/or longitude	3	1

4.2.5 Time Error (TE)

A time error is an error in the date/time field (minute, hour, day, month, year) which has been identified by the operator from log sheets or the speed check. The speed check indicates if a ship is travelling at greater than 25 knots. The date/time field may be replaced if the correct date/time is known, or retained if a corrected date/time cannot be determined.

Time errors can have either Accept or Reject GTSPP flags applied.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
TE Accept	Surface	5 to corrected date/time	2	1
TE Reject	Surface	3 to original date/time	3	1

4.2.6 Probe Type Error (PR)

A probe type error occurs when the operator selects the incorrect probe type at the time of deployment (for example, a T4 is selected, but a Deep Blue is deployed). If the correct probe type is known, the depth and temperature fields can be recalculated and the probe type changed. If the probe type is unknown, or there is no algorithm to correct temperatures/depths, the original probe type is retained and temperature and depth data is rejected.

Probe type errors can have either Accept or Reject GTSPP flags applied.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
PR Accept	Surface	5 to corrected probe type	5	5
PR Reject	Surface	3 to original probe type	3	3

4.3 Recorder QC

The components of the XBT system include a recorder that processes the data received over the fine wire link from the XBT via the launcher to the computer. This processor unit converts resistance to temperature and the software then transmits the data. Historically, some errors in temperature measurements have been attributable to specific recording systems. QC codes and flags relating to older systems (eg Protecno, BathySystems, Sippican Mk9) are summarised in Section 4.8, and the reader is encouraged to review Bailey et al (1994) for a full description of recorder errors in these older systems. QC of modern recording systems (for example, Sippican MK21, Turo Devil and Turo Quoll) requires only a few codes (Table 3).

Table 3. Summary of Recorder codes

QC code label	Code	Use Description	GTSPP Quality flag		
			Metadata	Temperature	Depth
Surface Transients or Surface Spikes	CS Reject	Usually applied to all profiles, surface startup transients occur from the surface to 3.6m (inclusive).	None	3 from the surface to 3.6m	1 from the surface to 3.6m
Depth Offset	DO Accept	Used when recording begins before probe enters the water, requiring the profile to be moved shallower in the water column, or if there is a delay in recording requiring the profile to be moved deeper in the water column	None	5 from the surface	1
	DO Reject	Used if the temperature data cannot be moved in the water column successfully to neighbouring profiles.	None	3 from the surface	3 from the surface
Test Probe	TP Reject	Data are from XBT recording system testing procedure and should not be included in data products.	4 to latitude and longitude	4 from the surface	4 from the surface

4.3.1 Surface Transients or Surface Spikes (CS)

Surface transients are caused by a minor start-up problem that leads to inaccurate temperature measurements in the top few metres of a temperature profile (Figure 3).

As described in the publication of Bailey et al (1994), the Australian XBT QC method in use for CS Accept was to routinely remove these surface spikes by replacing the temperature value with 99.99 from the surface to 3.6 m. GTSPP flag 5 was applied to temperature data at these depths. The CS Accept code is no longer in use and is now included in Section 4.8, Table 8.

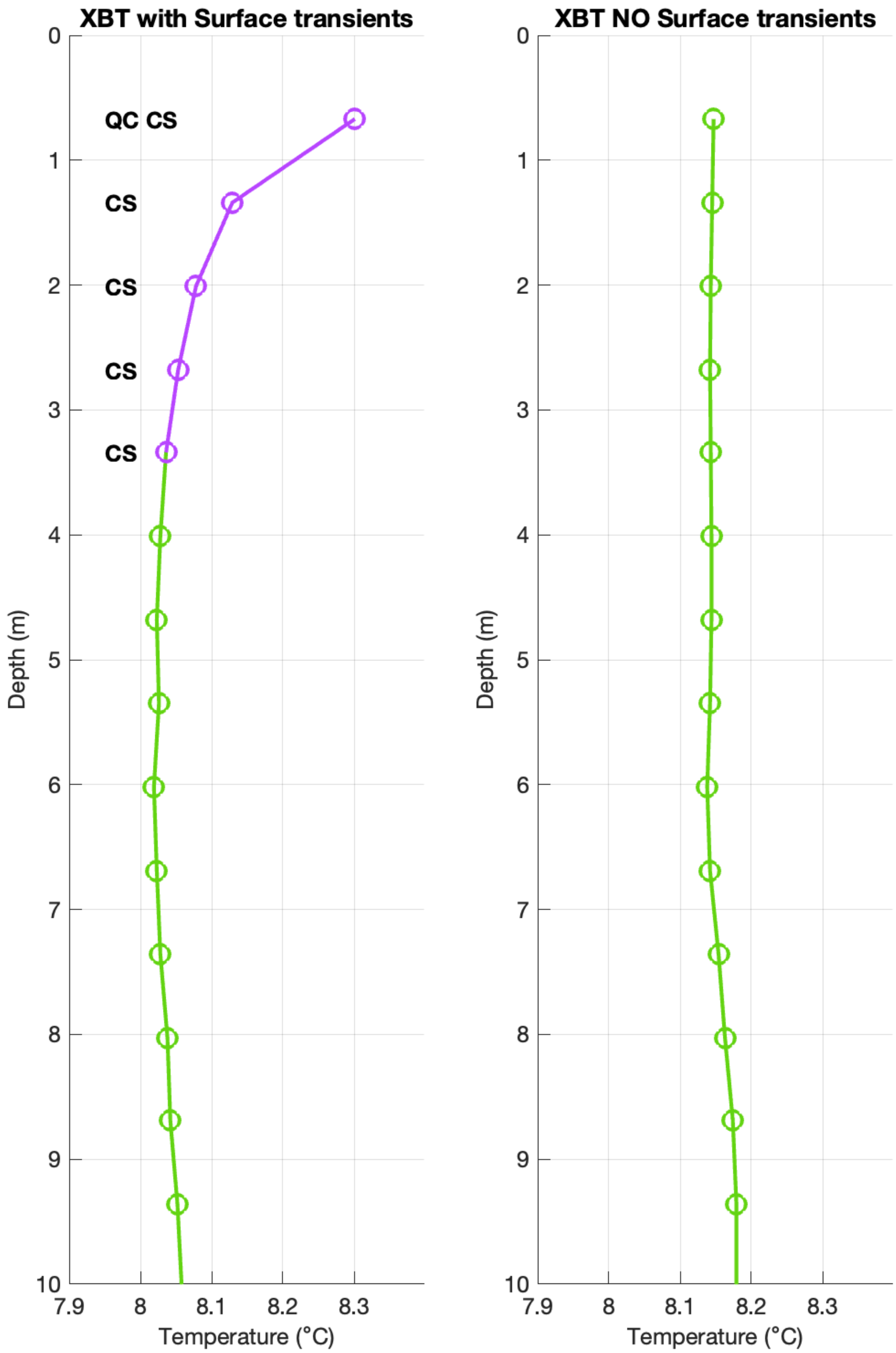
Since 2020/2021, the Australian QC group elected to retain the temperature surface values and apply a GTSPP flag 3 (Reject) to the surface transients from the surface to 3.6m. For historical Australian XBT data, the temperature data will be retrieved and GTSPP flag 3 applied retrospectively as profiles prior to 2020 are re-processed. Note that in Bailey et al (1989), the procedure described for use of CS Accept is ambiguous in the maximum depth of the failure (3.9m and 3.7m both used in the document, perhaps due to a mix of probe types in use).

The CS code is usually applied routinely to all XBT profiles undergoing scientific QC, with some exceptions where transients are not present. The user can elect to restore these values by ignoring the GTSPP 3 flags in the surface temperatures. The CS code is applied to each temperature and depth data point from 0 to 3.6 m depth, which results in repeated CS codes in data files.

The CS code is the only one applied where GTSPP flags of higher quality can be applied at deeper depths.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
CS Reject	Surface and all depths to 3.6m	3 (from the surface to 3.6 m depth)	1 (from the surface to 3.6 m depth)

Figure 3. Surface Transients example (CS). Two profiles from the same region showing the surface to 10 m depth with individual data points in circles. Left panel has CS applied (GTSPP flag 3, purple) with flag 1 (green) data deeper. The right panel shows a profile with no CS applied (GTSPP flag 1, green).



4.3.2 Depth Offset (DO)

In the XBT system, recording begins when the probe enters the water, closing the electrical circuit. In some cases, the electrical circuit in the system is closed early, resulting in the recording beginning prior to the probe entering the water (Figure 4). For example, if seawater is on the launcher pins and makes contact when the probe is loaded. The circuit can also be closed if a launcher cable is damaged.

In some cases, the data can be corrected by moving the temperature profile up in the water column to match the time the probe actually went into the water. In most cases, the temperature values are at full scale (>36.0°C) before the probe enters the water. Identification of the point at which the probe enters the water is done by finding the first temperature that is not full scale. Once the profile temperatures are moved, the temperatures from the upper part of the recording (when the probe was still in the launcher) are discarded. After the DO code, other codes should be applied (ie, the Quality Control Check (QC) and surface transient code (CS) and any other code that might be applicable).

If the data recording is delayed, the temperature profile may be rescued by moving it deeper in the water column to match neighbouring profiles. If the correct location cannot be determined, a reject code is selected (Figure 5).

In data quality controlled prior to 2023, the code used was PL Accept (see Section 4.8, Table 8) and the GTSPP flag applied was 2 to all temperatures.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
DO Accept	At the depth of first temperature that is not full scale.	5	1
DO Reject	From the surface	3	3

Figure 4. Depth Offset example (DO). Left panel shows the raw temperature data (heavy black) with neighbouring profiles. In the right panel, the entire temperature profile is moved up in the water column and GTSPP flag 5 (magenta) is applied to temperature data. QC, CS (purple), IV, RE codes are applied after DO.

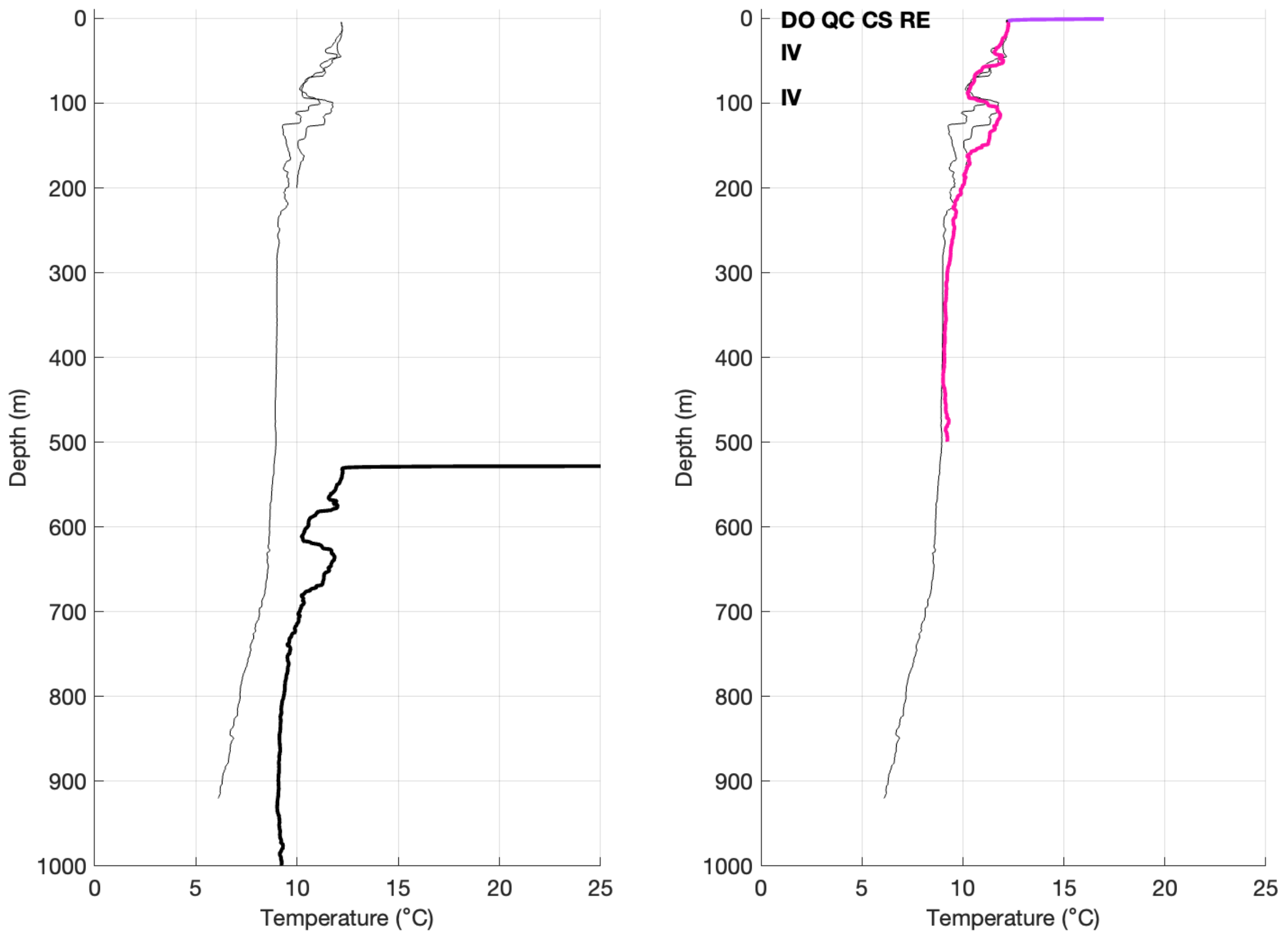
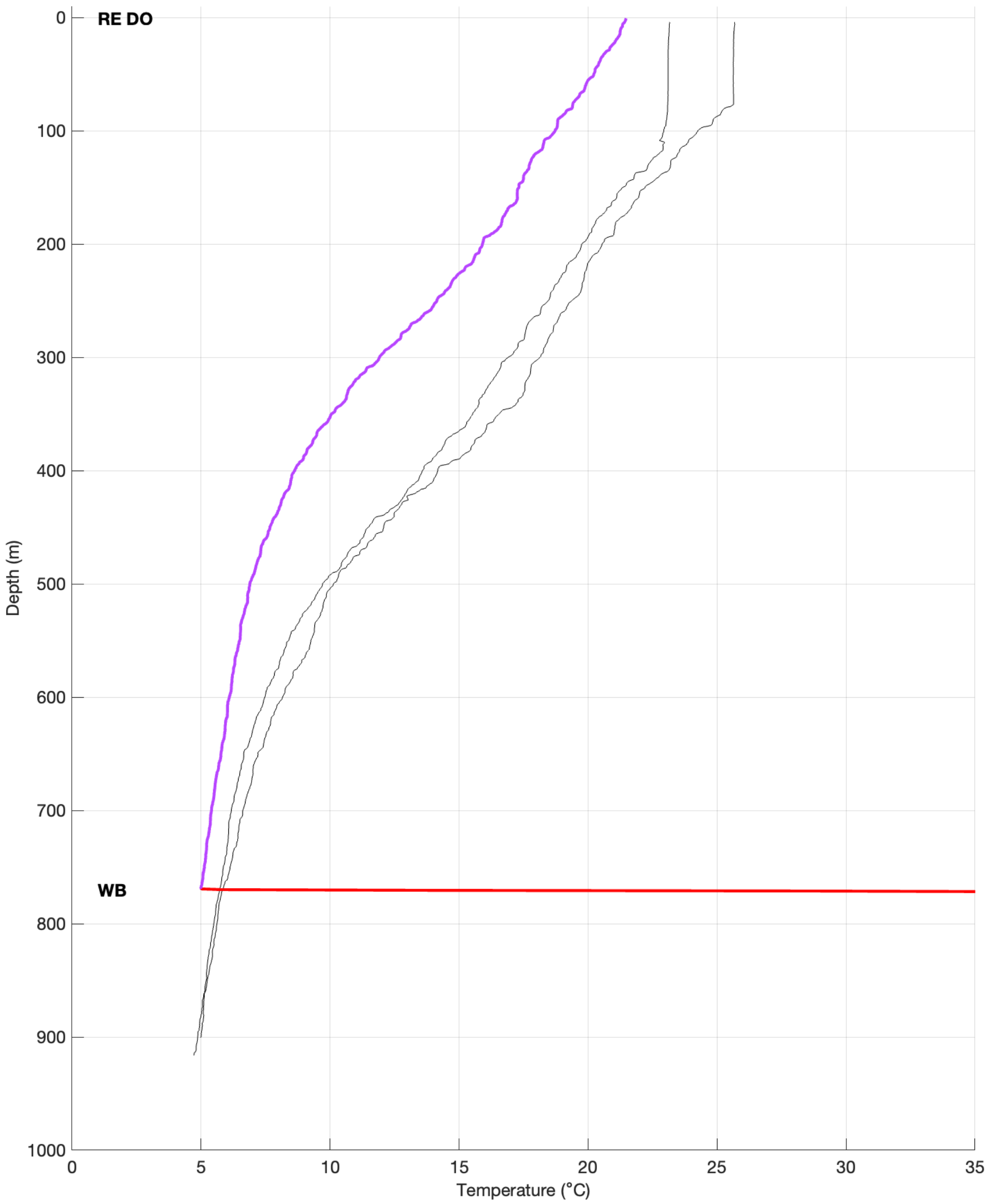


Figure 5. Depth Offset Reject example (DO). The entire temperature profile looks like it will match the repeat and neighbouring profiles (black), if moved deeper in the water column. The operator has chosen to reject the profile with GTSPP flag 3 (purple) as the tool to successfully move the profile was not available and a repeat profile was completed.

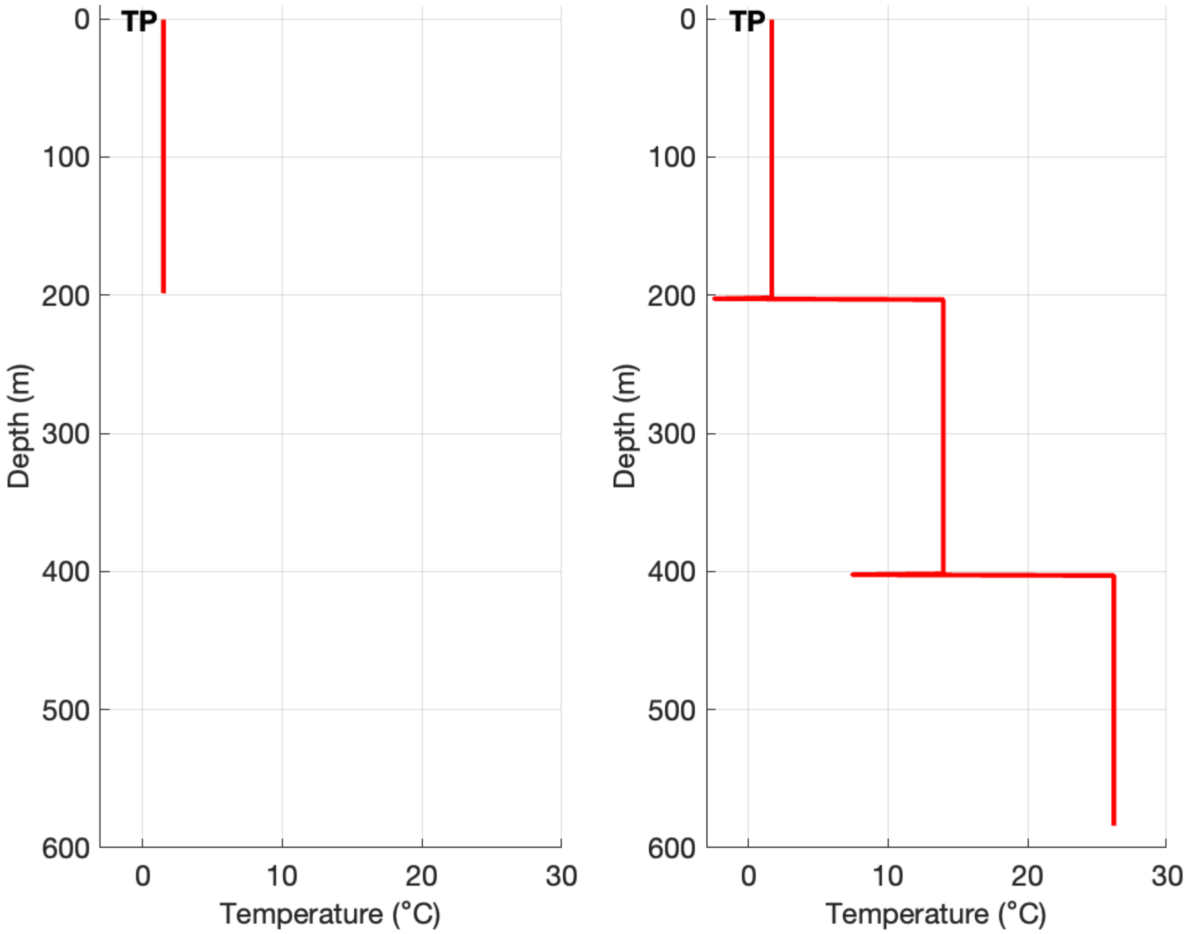


4.3.3 Test Probe (TP)

Test probes and devices are regularly used for testing or calibrating XBT systems (Figure 6). A test probe is recognised by a characteristic isothermal temperature profile, usually 1.5°C ±0.15°C. In some cases, multi-point test probes are used and the test profile is split into 2-3 isothermal sections. In some systems (eg the Turo systems in use in Australia), 'test' may be present in the serial number field or in the file name. In data collected using Turo recording systems, all test probes have the latitude and longitude values automatically set to 25.35° S and 131.03° E, located in the centre of Australia.

Code	Depth of application	GTSPP Quality flag		
		Metadata	Temperature	Depth
TP Reject	Surface	4 to latitude and longitude	4	4

Figure 6. Test Probe example (TP). TP is applied at the surface, and the entire temperature and depth data are rejected with GTSPP flag 4 (red). Left panel shows a typical single-resistance test canister. Right panel shows a typical multi-resistance test canister with spiking where transition is made between resistance changes.



4.4 Profile data QC

The profile data quality control codes include identifying malfunctions that are routinely observed, and which require interpolation, deletion or filtering of the data (Table 4). These include wire breaks and various types of outside electrical interference that can result in spikes and high frequency noise. Many of the electrical interference type errors can be interpolated or filtered with the remaining temperature records being unaffected. If the interference is severe this will not be the case, and the quality of the remainder of the temperature records in the profile will be downgraded. Also included in this category are cases where the probe hits the bottom and data below this depth must be rejected.

Table 4. Profile data QC codes

QC code label	Code	Use Description	GTSPP Quality Flag	
			Temperature	Depth
Wire Break	WB Reject	Apply from depth where the temperature profile exhibits a sudden deflection to high or low temperature end of scale.	4 from depth of wire break	1
Hit Bottom	HB Reject	Indicates the depth of actual hit bottom location. HB is usually paired with the NG code either at the same depth or within 50m.	3 from depth of hit bottom event	3 from depth of hit bottom event
No Good Profile/ Unknown fault	NG Reject	Indicates all data below this point are bad, usually for a reason that cannot be identified. HB is usually paired with NG.	4 from depth of anomaly	1
Electrical Interference	EI Accept	Interpolation possible: Electrical interference (spikes or insulation penetrations) occur at one or more depths and do not impact on the deeper temperature data. The temperatures at affected depths are replaced with interpolated temperatures.	5 for data that has been interpolated, then 2 for data at depths deeper than interpolated section	1
	EI Reject	Interpolation not possible: Electrical interference (spikes or insulation penetrations) occur at one or more depths and impact on the deeper temperature data in the profile.	4 from depth of Electrical Interference	1
High Frequency Noise	HF Accept	Filtering possible: high frequency noise occurs at one or more depths and does not impact on the deeper	5 for data that has been filtered, then 2 for depths	1

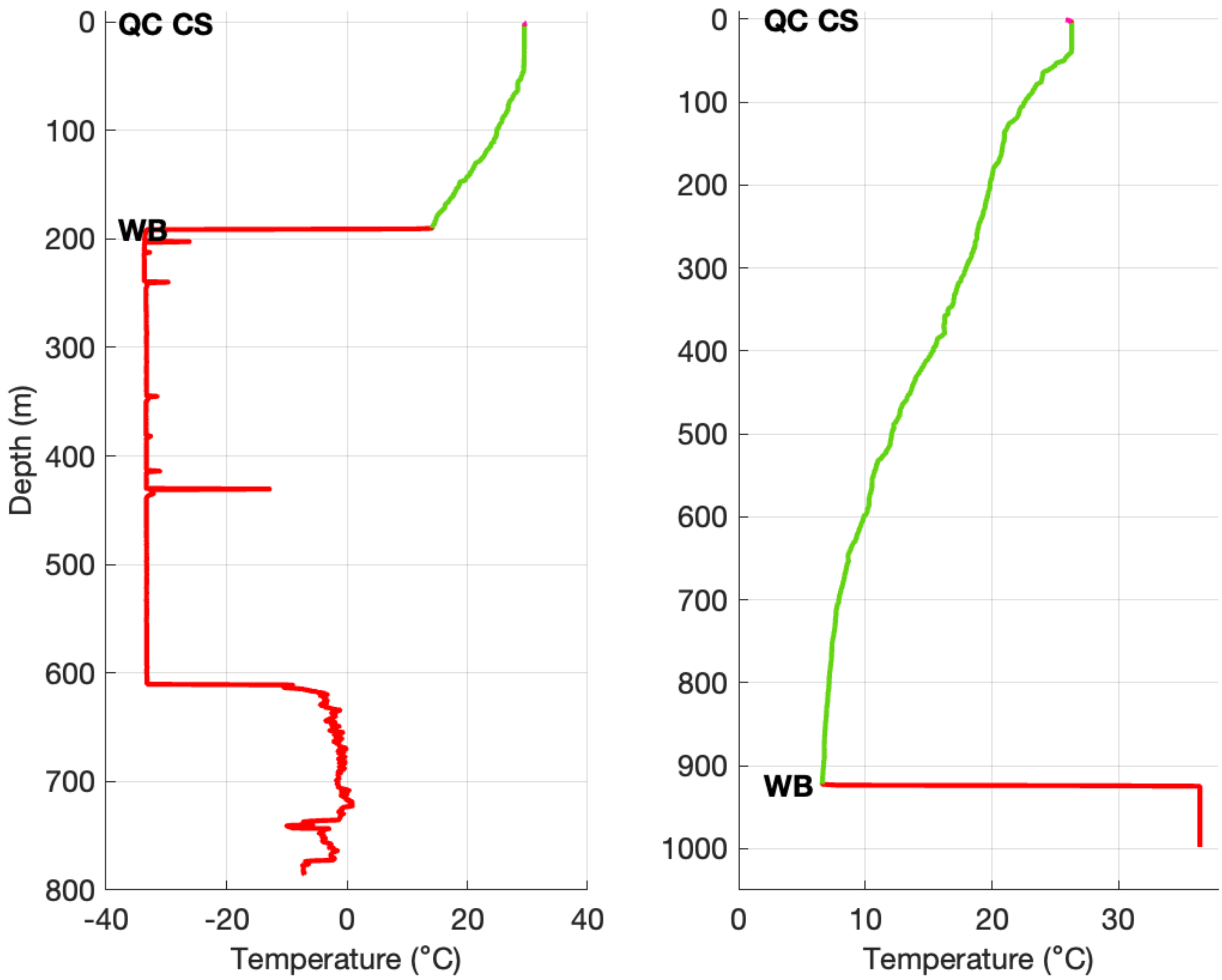
QC code label	Code	Use Description	GTSPP Quality Flag	
			Temperature	Depth
		temperature data. The temperatures at affected depths are replaced with filtered temperatures.	deeper than filtered section	
	HF Reject	Filtering not possible: high frequency noise occurs at one or more depths and impacts on the deeper temperature data in the profile.	4 from depth of noise	1
Constant Temperature Profile	CT Accept	Apply if surface temperature of an isothermal profile is considered consistent (valid) with neighbouring profiles.	1 from surface	1
	CT Reject	Apply from the depth where an isothermal profile is considered inconsistent with neighbouring profiles.	3 from depth where temperature divergence occurs	3 from depth where temperature divergence occurs

4.4.1 Wire Break (WB)

When the XBT wire breaks, a short circuit causes the temperature readings to go off scale either to the low (wire breaks from the spool in the launcher) or to the high (wire breaks from the descending probe's spool) temperature end of the scale (Figure 7). The main causes of wire breaks can be fouling or if the terminal depth of the probe is reached (ie, a good XBT cast in deep water ends with a wire break). Often a Wire Stretch (WS) will precede a wire break.

Code	**Depth of application**	**GTSPP Quality flag**	
		Temperature	**Depth**
WB Reject	At depth of first temperature deflection to high or low scale.	4	1

Figure 7. Wire break examples (WB). (GTSPP flag 4, red)



4.4.2 Hit Bottom (HB)

After the probe hits the bottom, the temperature trace usually appears isothermal (as the fall rate equation still assumes the probe to be descending) or warms slightly (due to self-heating of the thermistor when the probe ceases falling). Contact with the bottom is often indicated by a small horizontal spike which can be warmer or colder (Figure 8). The spike can be due to overheating of the thermistors or physical contact with the bottom. Bathymetry maps (such as shown in Figure 9, NCAR, 1995) can be used to assist with diagnosis of bottom hits. Data recorded beyond the hit bottom event is rejected. The HB code is usually paired with a NG code to downgrade the quality to GTSPP flag 4. In cases where there is no bottom spike apparent, the NG code may be placed anywhere within 50 m deeper of the HB code at the operator's discretion.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
HB Reject	At the depth indicated by a spike in temperature or at the operator's best estimate of bottom depth.	3	3

Figure 8. Hit Bottom (HB) examples. Left panel, HB (GTSPP flag 3, purple) and NG (GTSPP flag 4, red) placement example where no HB spike is present. Right panel, example of HB and NG placement when HB spike is present. Both panels show neighbouring profiles (black) and have zoomed sub-panels showing the HB region.

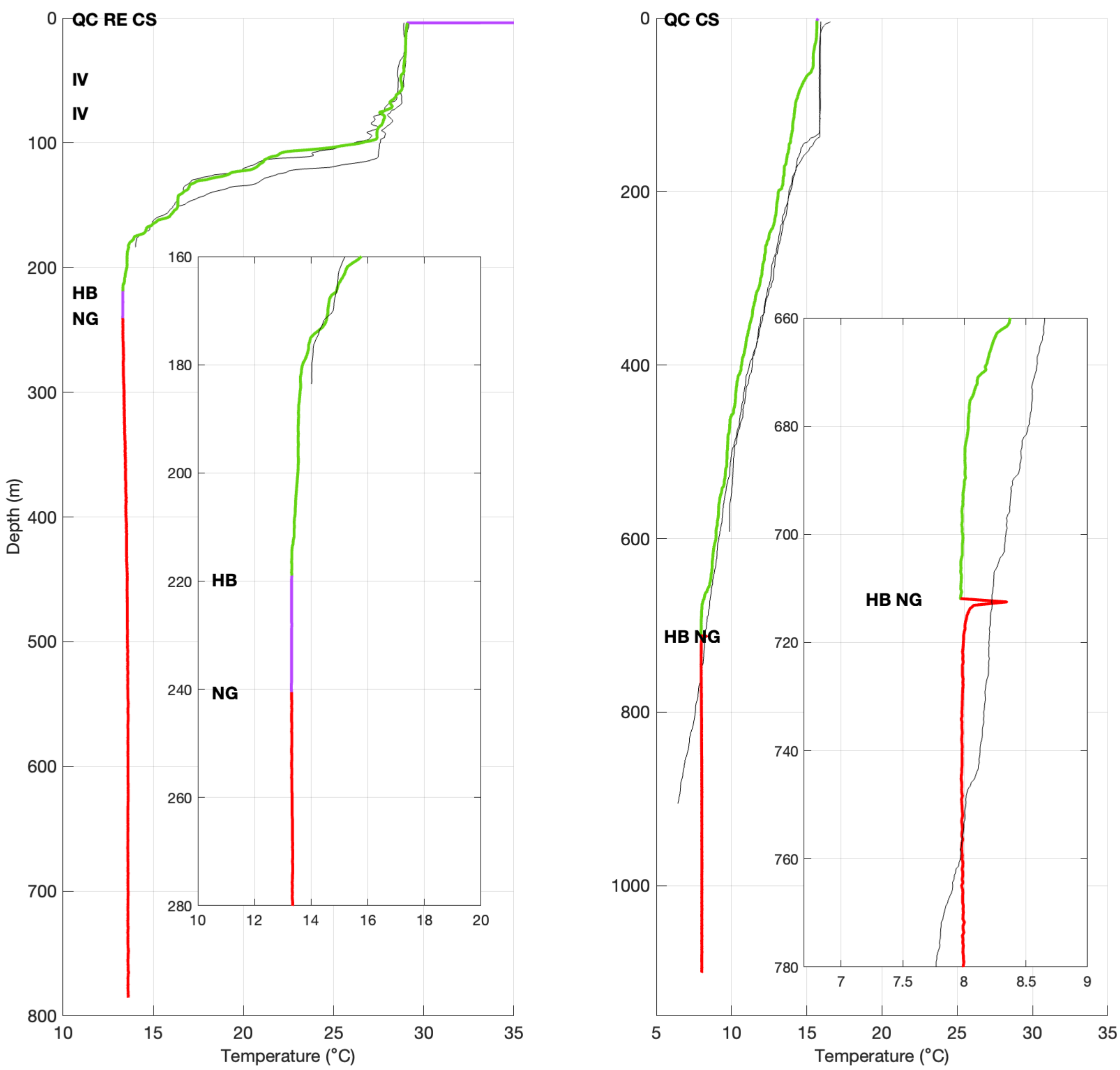
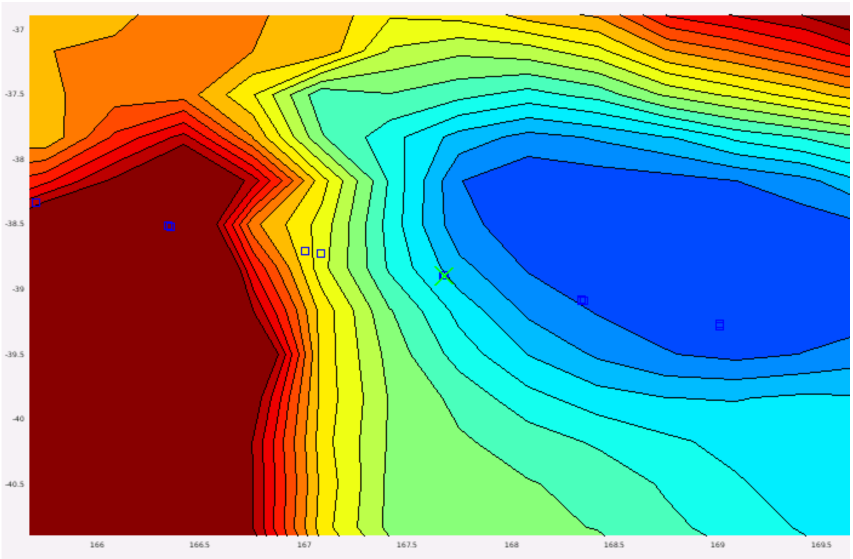


Figure 9. Bathymetry in the region of profiles that have HB flags applied. Squares indicate the location of profiles and bathymetry is >2000m in dark red region <400m in blue region. Green cross is the location of the profile in the right panel of Figure 7.

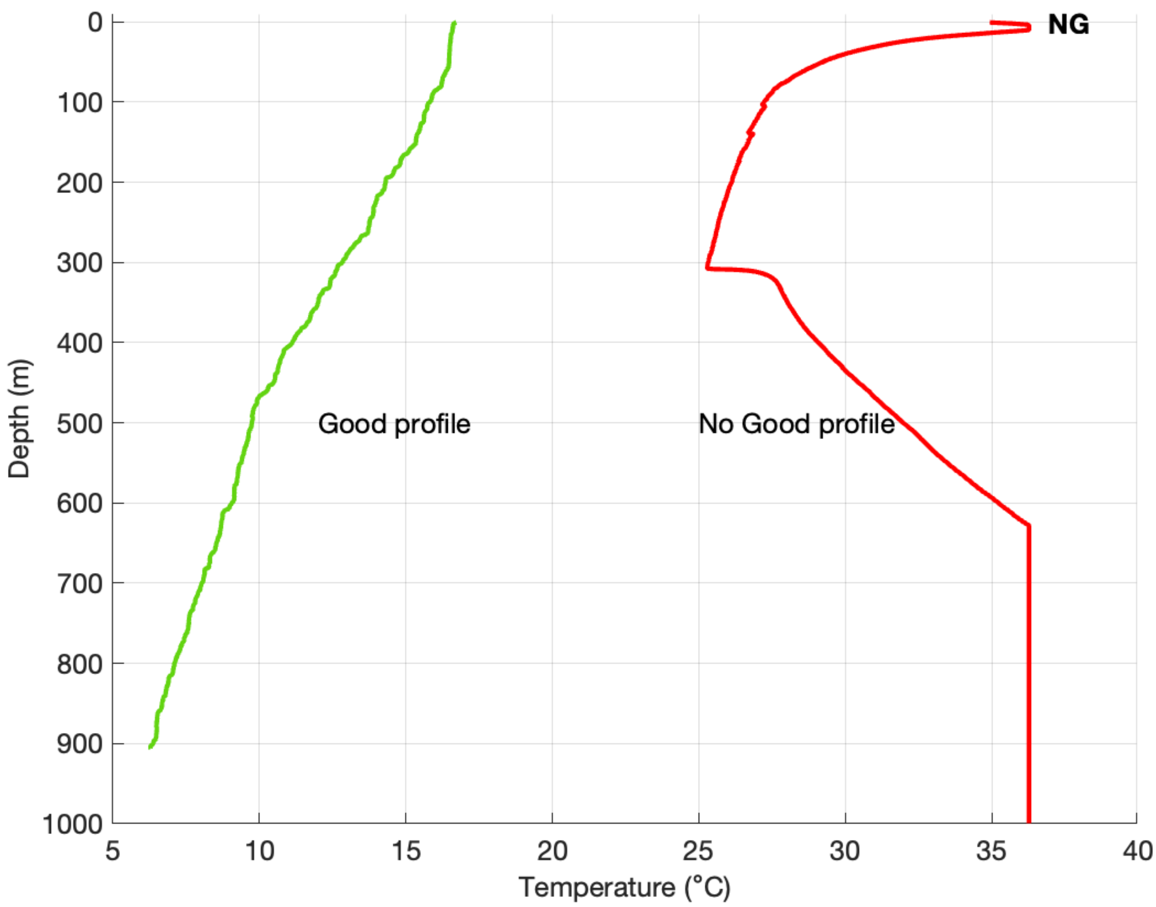


4.4.3 No Good (NG)

A No Good indicator is used when the temperature data are completely and obviously erroneous. It can be used for any failure for which the operator cannot confidently apply a known failure code (Figure 10). NG is also used to downgrade the quality of data from GTSPP flag 3 to GTSPP flag 4, for example: HB is usually paired with NG to downgrade the temperature data below a hit bottom to GTSPP flag 4.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
NG Reject	At the depth where the temperature profile is anomalous.	4	1

Figure 10. No Good example (NG). (GTSPP flag 4, red).



4.4.4 Electrical Interference and Insulation Penetrations (EI)

Electrical Interference encompasses failures that may be fixable with interpolation applied (Figures 11 and 12). Isolated or intermittent spikes in the temperature record can be the result of external electrical or electromagnetic interference that influences the XBT system's output. Ship's radio signals, lightning and XBT wire touching the side of the ship or infrastructure can often cause spikes in the profile. Interference may appear severe but, in some cases, the temperature records can be successfully interpolated by interpolation.

An insulation penetration appears as a sharp spike(s) towards the high temperature end of the scale, generally followed by a gradual recovery. This is caused by damage to the wire insulation. The insulation damage will tend to heal itself by the interaction between the wire and seawater. (Note: insulation penetration is a special form of leakage (LE)).

Interpolation of temperature data is applied if the interpolated section compares well to neighbouring and/or historical profiles, and the remaining temperature records are unaffected after interpolation. GTSPP Accept flags are applied (5 to interpolated section and 2 to temperatures deeper). Temperatures are replaced with linearly interpolated data for the affected section. If severe noise (>0.2°C) occurs which cannot be interpolated successfully, and the deeper temperature records are considered unreliable, retain the temperature data and apply GTSPP Reject flags.

The algorithm for interpolation of EI faults is given in Appendix D. In historical data (prior to 2023), the QC codes IP and SP were used with GTSPP flag 2 applied to temperature (see Section 4.8, Table 8).

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
EI Accept	At the depth of the first noise occurrence.	Interpolated section: 5 Data at depths deeper than interpolated section: 2	1
EI Reject	At the depth of the first noise occurrence.	4	1

Figure 11. Spike examples with EI code applied. Left panel, EI reject (GTSPP flag 4, red); Centre panel, EI with spike still shown; Right panel is the final result of EI accept interpolation (GTSPP flag 5, magenta, and 2 at deeper depths, blue).

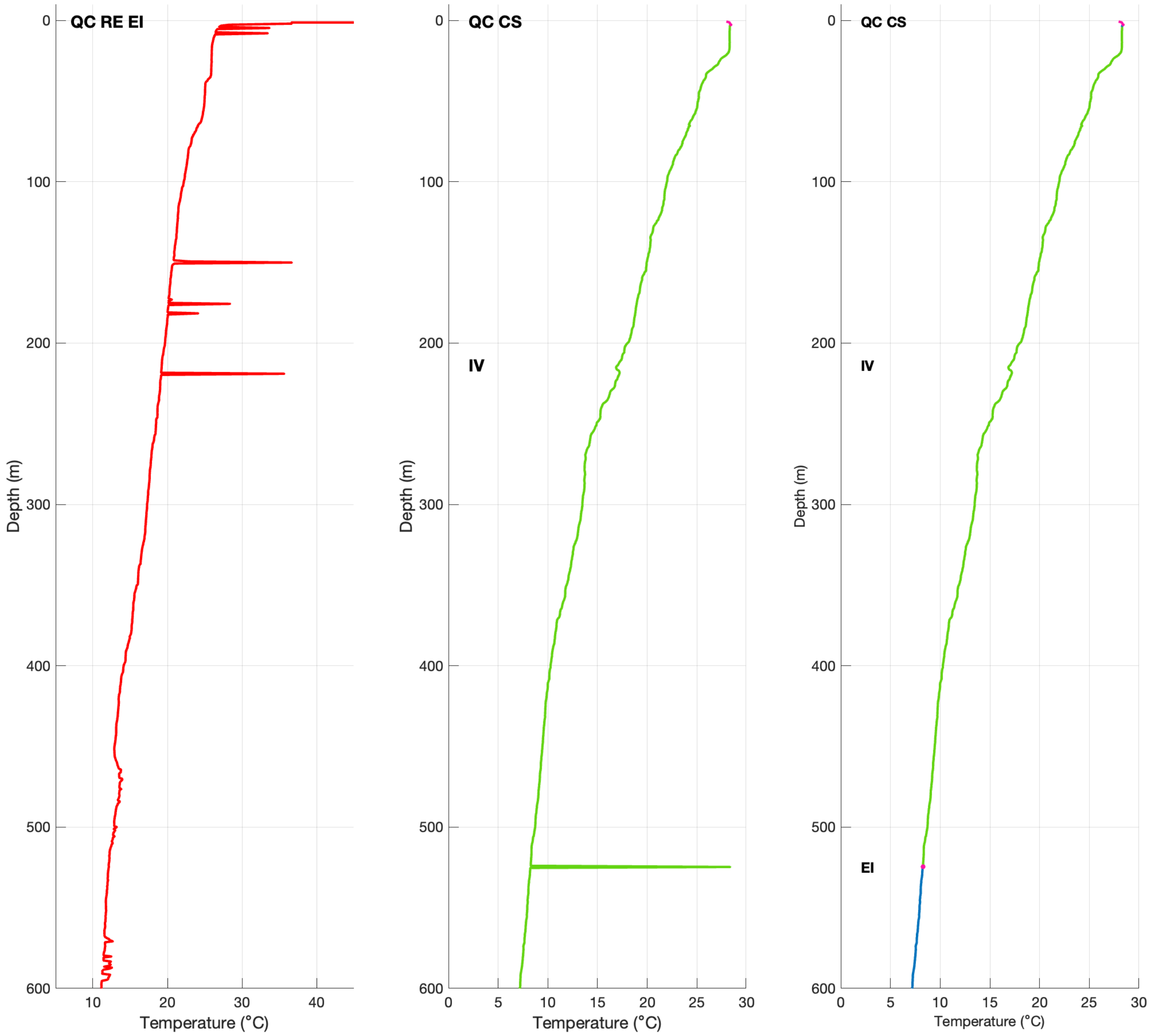
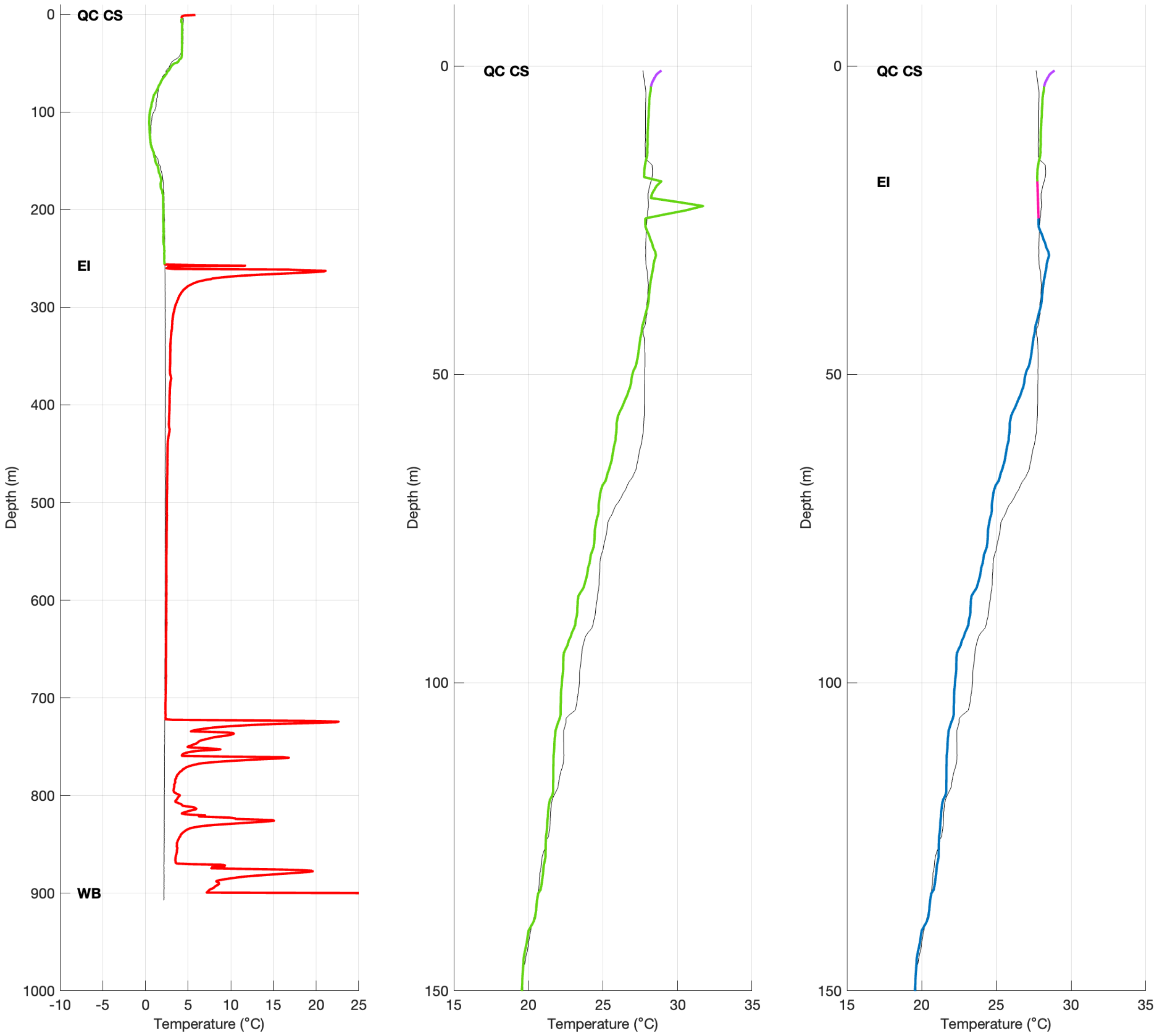


Figure 12. Insulation Penetration examples with EI code applied. Left panel, EI reject (GTSPP flag 4, red); Centre panel, insulation penetration still shown; Right panel is the final result of EI accept (GTSPP flag 5, magenta and 2, blue), with interpolated temperature data. Black lines are neighbouring profiles.



4.4.5 High Frequency Noise (HF)

High frequency noise (continual spiking over a wide range of depths) in the temperature record can be the result of external electrical or electromagnetic interference that influences the XBT system's output (figures 13 and 14). Ship's radio signals, lightning and XBT wire touching the side of the ship or infrastructure can often cause spikes in the profile. Interference may appear severe, but in some cases, the temperature records can be successfully interpolated by filtering.

HF is applied at the depth of the first noise occurrence. Filtering of temperature data is applied if the filtered section compares well to neighbouring and/or historical profiles, and the temperature data deeper than the filtered section are unaffected after filtering. Replace temperatures with filtered data. If severe noise (>0.2°C) occurs which cannot be filtered successfully, and the deeper temperature records are considered unreliable, retain the temperature data and apply GTSPP Reject flags.

The algorithm for filtering of high frequency noise is given in Appendix E.

Code	**Depth of application**	**GTSPP Quality flag**	
		Temperature	**Depth**
HF Accept	At the depth of the first noise occurrence.	Filtered section: 5 Data at depths deeper than filtered section: 2	1
HF Reject	At the depth of the first noise occurrence.	4	1

Figure 13. High frequency noise with correctly applied HF interpolation filter. Left panel shows high frequency interference prior to QC application. Right panel shows final QC'd profile with filtered temperature data (GTSPP flag 5, magenta, for filtered section and flag 2 deeper, blue). Repeat profile is shown in black in both panels.

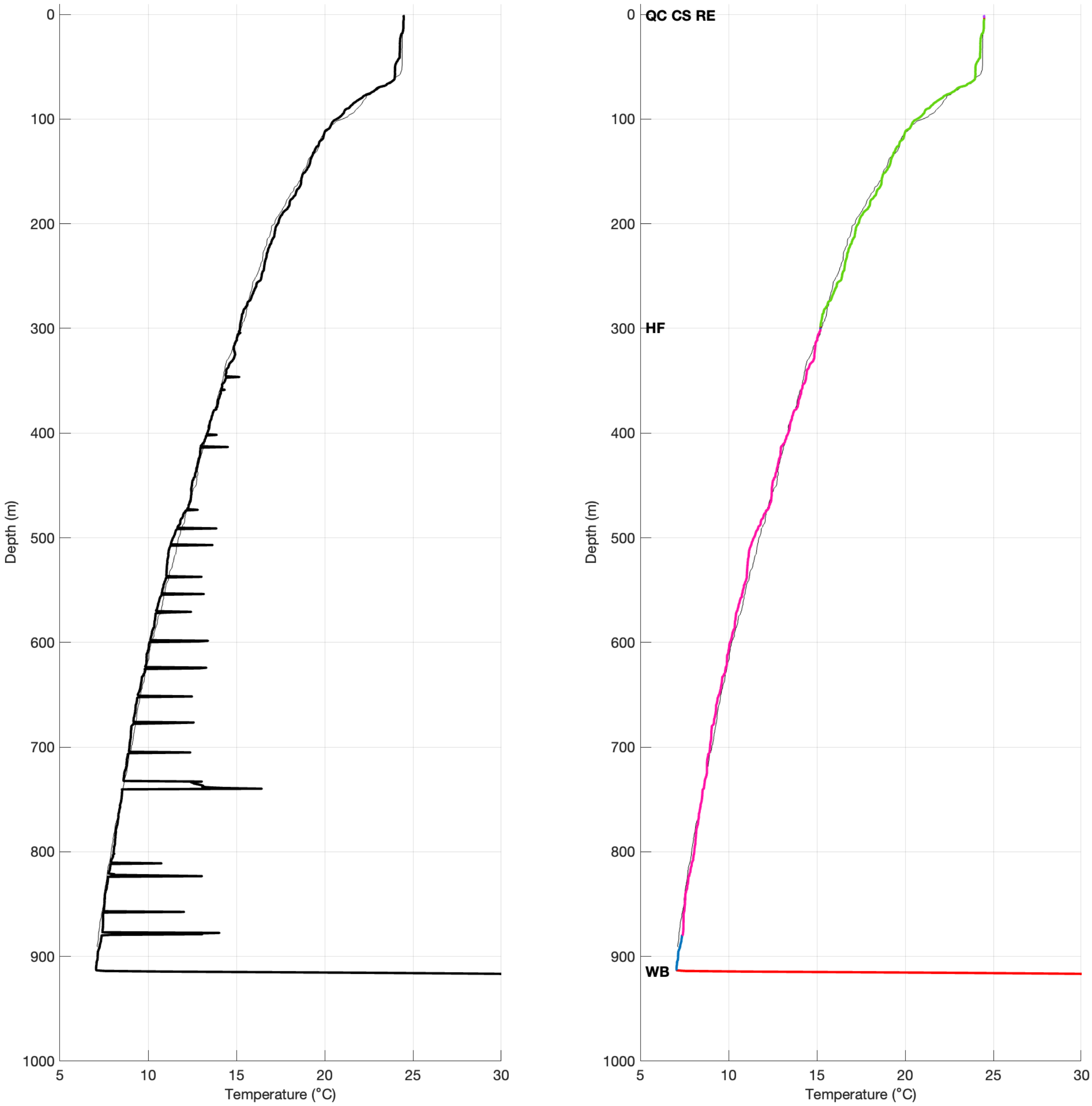
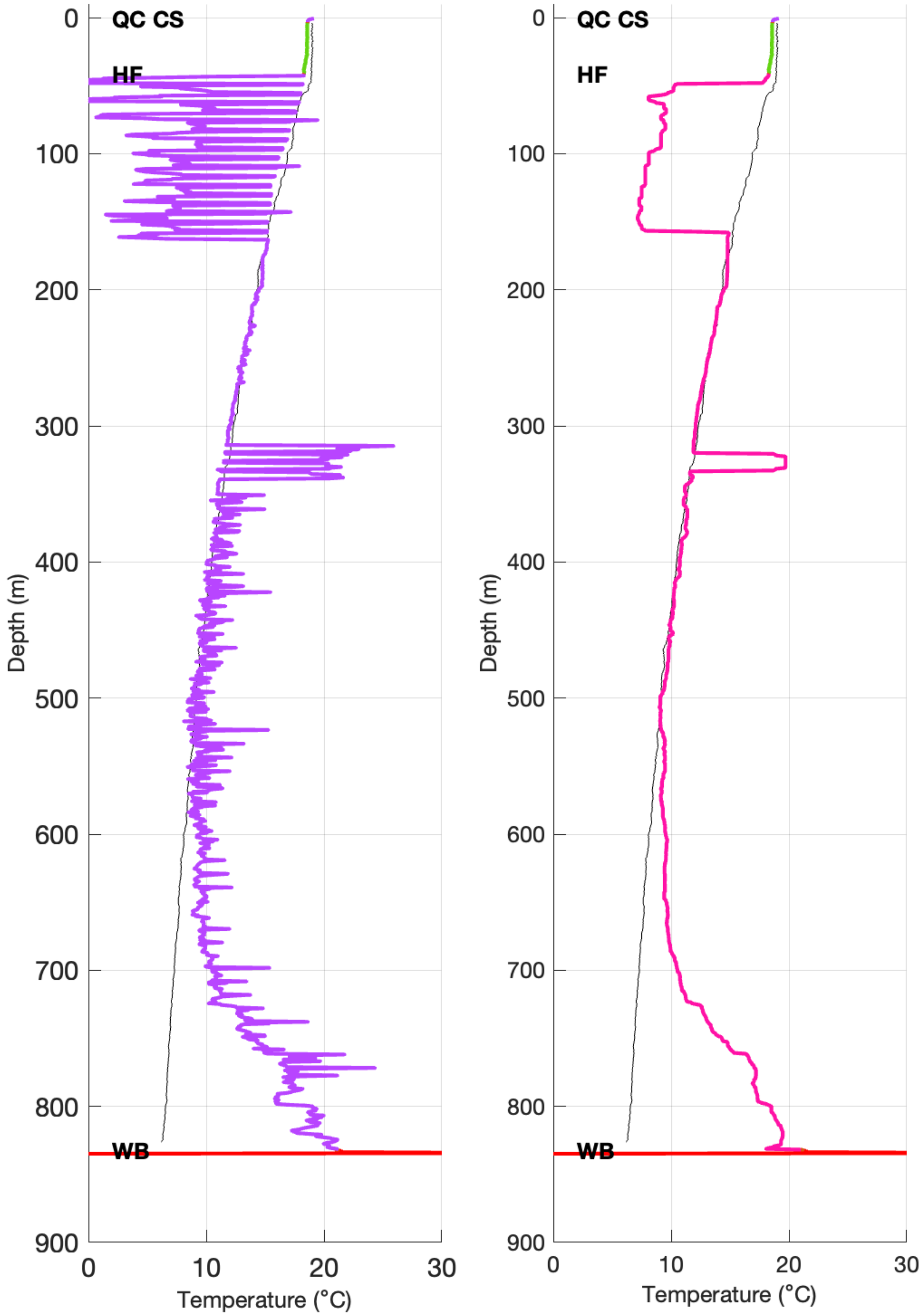


Figure 14. High frequency noise with incorrectly applied HF filter. HF reject (GTSPP flag 3, purple), left panel shows high frequency interference with HF reject applied correctly, right panel shows how filtering does not correct the failure. A good profile is shown in black.



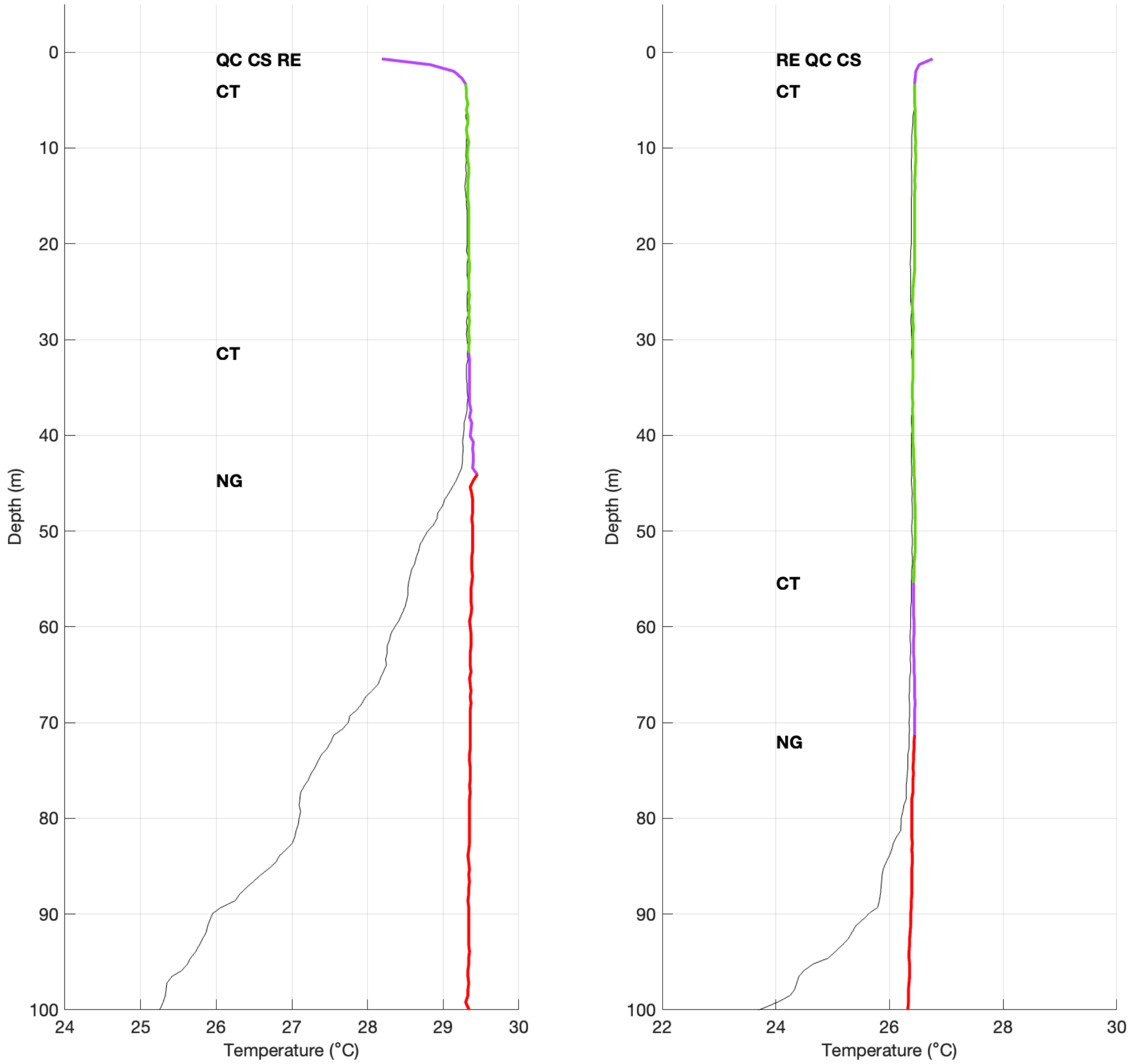
4.4.6 Constant Temperature Profile (CT)

A constant temperature profile is a record of temperature data that appears isothermal (Figure 15). In many cases, a real constant temperature is often seen at in the surface layer but continues beyond the surface anomalously. A constant temperature failure is often the outcome of a faulty probe (broken thermistor or the weighted nose has broken off the probe) resulting in the system's inability to detect a change in resistance and hence temperature. This fault should not be confused with Test Probes (TP). For CT Reject faults the cause is assumed to be the result of a broken nose cone so both depth and temperature quality are downgraded.

Apply CT if the temperature appears isothermal. The CT region may be consistent on cross checking with neighbouring profiles and GTSPP Accept flags should be applied from the first depth of the isothermal region. GTSPP Reject flags should be applied from the depth where constant temperatures are inconsistent with neighbouring profiles or climatology.
The NG code may be used to downgrade the CT region to GTSPP quality flag 4.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
CT Accept	At the first depth that temperature is consistent with neighbouring profiles.	1	1
CT Reject	At the depth of the first difference from neighbouring profiles.	3	3

Figure 15. Constant Temperature examples (CT). CT accept (green, GTSPP flag 1) and CT reject (purple, GTSPP flag 3). Repeat (good) profile is shown in black.



4.5 Inversion and Wire Stretch QC

Temperature inversions are common, real features of the ocean. An inversion is a stable increase of temperature with depth as a result of compensating salinity structure and is identified by a characteristic bulge to the high temperature side of an XBT profile. There is, however, a class of malfunctions (wire stretch) which can look very similar. Distinguishing between the two can be difficult. Whereas an inversion is a real increase of temperature with depth, a wire stretch because of an increase in tension in the wire (due to poor unreeling) can result in a similar bulge to the high temperature side of an XBT profile. The approach taken in the quality control of profiles showing an increase in temperature with depth, therefore, is to be conservative. Only those features that have either been confirmed by a check between neighbouring profiles (usually repeat drops) or have been observed in an area where inversions are known to occur are coded as inversions. Unconfirmed features are coded according to the degree of confidence we have in them. If the warming is suspected to be erroneous it should be coded as a wire stretch.

Table 5. Inversion and Wire Stretch codes

QC code label	Code	Use Description	GTSPP Quality Flag	
			Temperature	Depth
Inversion	IV Accept	Confirm inversion (warming) or nub (warming in surface layer) with neighbouring profiles and repeat drops.	1 from depth of inversion	1
	IV Accept	No confirmation of inversion (warming) in neighbouring profiles, but the area is known for inversions and/or inversions are seen in historical profiles.	2 from depth of probable inversion	1
Wire Stretch	WS Accept	Use if similar features are not observed in neighbouring drops, inversions are unlikely in the area and warming is small (<0.2°C).	2 from depth of possible wire stretch	1
	WS Reject	No confirmation of warming, inversions are unlikely in the area and warming is large (>0.2°C) or warming occurs close to the wire break.	3 from depth of wire stretch	1

4.5.1 Inversions (IV)

An inversion is defined as an increase in temperature with depth observed at some point in the profile (Figure 16). A nub is a type of inversion where an increase in temperature with depth is observed within or at the base of the mixed layer (Figure 17). GTSPP flag 1 is applied to temperature data where confirmation of the inversion is observed in repeat or neighbouring observations. In a situation where no neighbouring or repeat drops are available, inversions might be visible in historical observations, in which case an GTSPP flag 2 should be applied to temperature data (Figure 18). These features usually occur in specific regions.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
IV Accept	At the depth of the first warming of the inversion	1	1
IV Accept	At the depth of the first warming of the probable inversion	2	1

Figure 16. Inversion examples (IV). Repeat profiles collected 12 minutes apart, with inversions confirmed (green, GTSPP flag 1). Note the inversions occur at different depths as the ship moves through the frontal region.

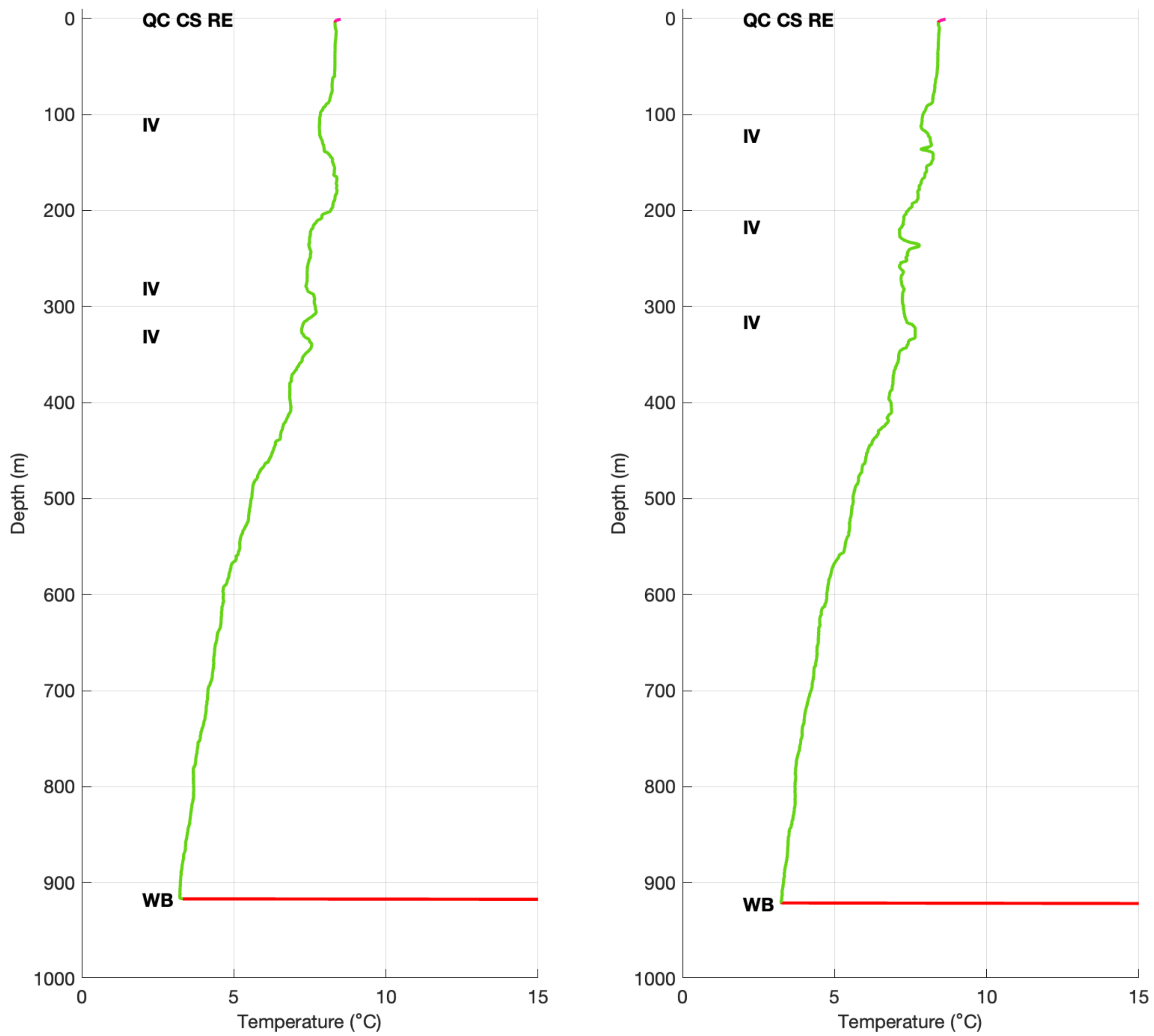


Figure 17. Nub inversion examples (IV). Repeat profiles showing a confirmed nub, IV accept (GTSPP flag 1, green) in both profiles.

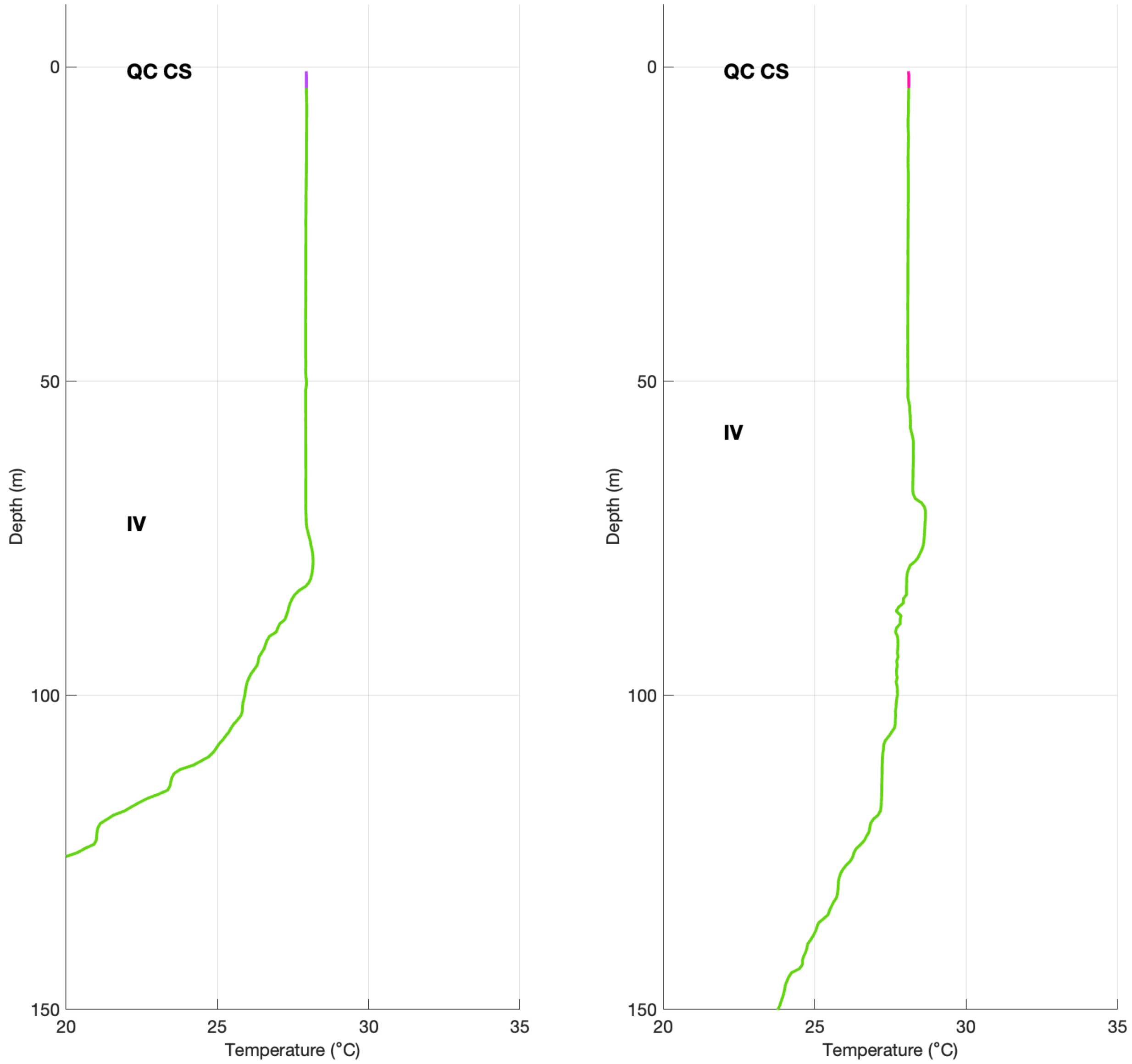
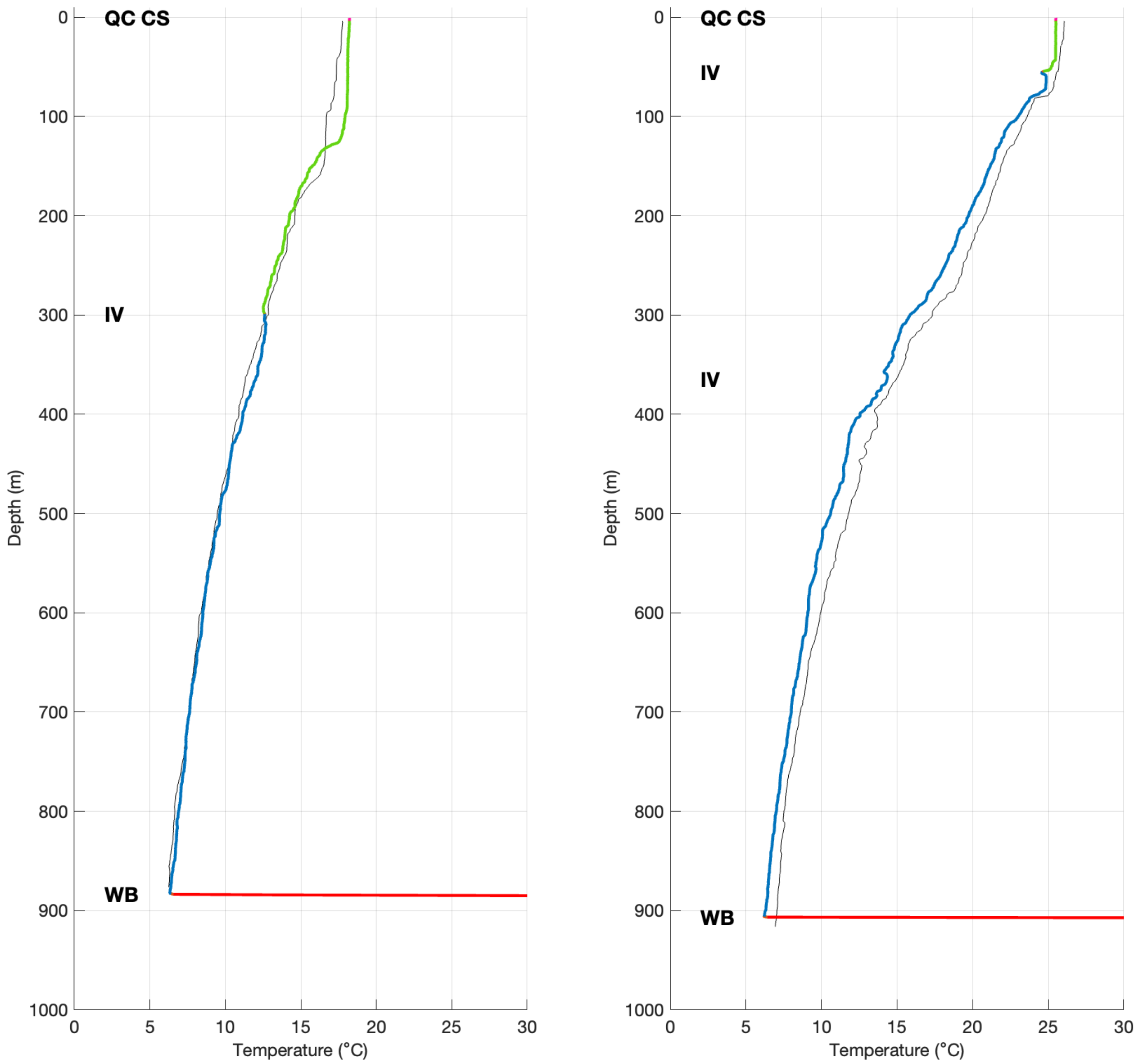


Figure 18. Inversion GTSPP flag 2 (probable inversion) examples (IV). IV accept (flag 2, blue) where inversions are expected in the region, but no confirmation in neighbouring profiles (black) is seen. The right panel shows a confirmed inversion below a probable inversion.



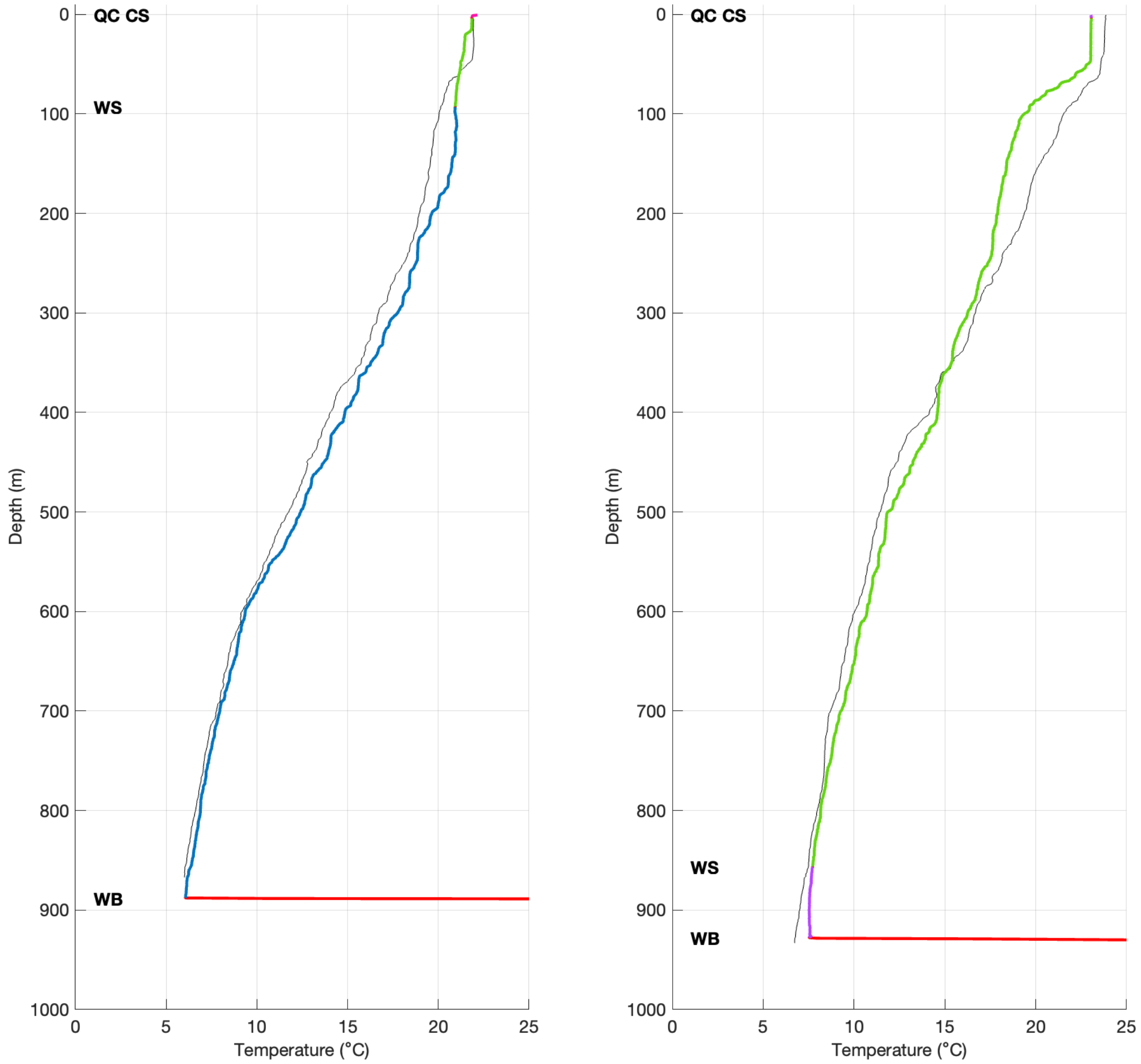
4.5.2 Wire Stretch (WS)

A wire stretch is an apparent warming of temperature with depth at some point in the profile (<0.2°C from temperatures immediately above) which does not occur in neighbouring or historical profiles (Figure 19) and in regions where inversions are not found. The Wire Stretch is accepted if the magnitude of the inversion/warming is <0.2°C from temperatures immediately above and/or there is also not enough evidence to completely doubt the quality of the profile.

A wire stretch is most often observed at the base of a profile before a wire break and occurs at shallower depths if fouling or restricted unreeling occurs.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
WS Accept	At the depth of the first warming of the wire stretch	2	1
WS Reject	At the depth of the first warming of the wire stretch	3	1

Figure 19. Wire stretch examples (WS). Left panel shows WS accept (GTSPP flag 2, blue) with neighbouring profile (black). Note the profile temperatures are similar below 550m, wire stretch does not impact on the overall profile quality. Right panel, WS reject (GTSPP flag 3, purple) above a wire break where temperature warms compared to neighbouring profile (black).



4.6 Structure and Signal Leakage QC

Temperature profiles in the upper layers of the ocean can exhibit many types of real, fine scale structure that are generated by a variety of small scale mixing and turbulent processes (Table 6). Fine structure specifically refers to structure in the hydrographic and flow fields of the ocean, on vertical scales of 1-100 metres. These are usually associated with horizontal scales of 1 m to 10 km and time scales of one minute to several days (McPhaden, 1985). One type of malfunction (leakage) can also result in temperature profiles with characteristics similar to fine scale structure. As was the case for inversions, it is often difficult to distinguish between the real feature and the malfunction so verification with repeat or neighbouring observations and historical observations from the region are used for confirmation. Fine scale structure resulting from small scale mixing processes is commonly observed in a temperature profile as many small step-like features or interleavings. Leakage may show similar characteristics, but the small-scale structure in leakage is often sharper and the temperatures below the depth of the anomaly will tend to be warmer when compared with repeat or neighbouring profiles.

Table 6. Structure and Signal Leakage codes

QC code label	Code	Use Description	GTSPP Quality Flag	
			Temperature	Depth
Fine or Step-Like Structures	**ST Accept**	Used if highly structured step-like features or fine structure are confirmed in a neighbouring or repeat observations.	1 from the surface	1
	ST Accept	Used if structured step-like features or fine-scale structure cannot be completely confirmed by a repeat or neighbouring profile, but similar features have previously been observed in the region.	2 from the surface	1
Leakage	**LE Accept**	Used if the shape of the feature is characteristic of signal leakage but the magnitude of the anomaly is small enough (~0.2°C over a range of depths) not to seriously affect the overall quality of the data and/or there is not enough evidence to completely doubt the profile.	2 from the surface	1
	LE Reject	Used if leakage is observed as erratic, sharp and unrealistic structure over a range of depths or the entire profile. Temperatures at depths below the first appearance of leakage are generally warmer than neighbouring profiles.	3 from depth of leakage	1

4.6.1 Fine or Step-Like Structure (ST)

Step-like structure consists of step-like features or small interleaving observed in a profile over a range of depths, (usually 10-100 m) or the entire profile (figures 20 and 21). Thermostads, well-mixed regions where temperature and density vary little with depth, also appear as step-like features and so are included in this category. This feature can occur in many regions.

Fine structure appears as small-scale structure superimposed on the temperature profile over a range of depths (usually 10-100 m) or in the entire profile. It often appears as small scale interleavings in the temperature profile.
If step-like structures are present in a neighbouring or repeat observations GTSPP flag 1 is applied to all temperature data from the surface. ST is applied to the original, and any repeat/neighbouring profiles that exhibit the structures. ST probable (GTSPP flag 2) is applied to temperature data if step-like structures are observed in a profile but are not confirmed by a repeat or neighbouring profile. Similar features are seen in historical observations from the region.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
ST Accept	At the surface to all repeat/neighbouring profiles with step-like structures	1	1
ST Accept	At the surface of a profile with no confirmation from repeat/neighbouring profiles	2	1

Figure 20. Step-Like structure example ST accept (GTSPP flag 1, green). Two neighbouring profiles collected within 10 minutes of each other. Staircase like structure are seen in both profiles.

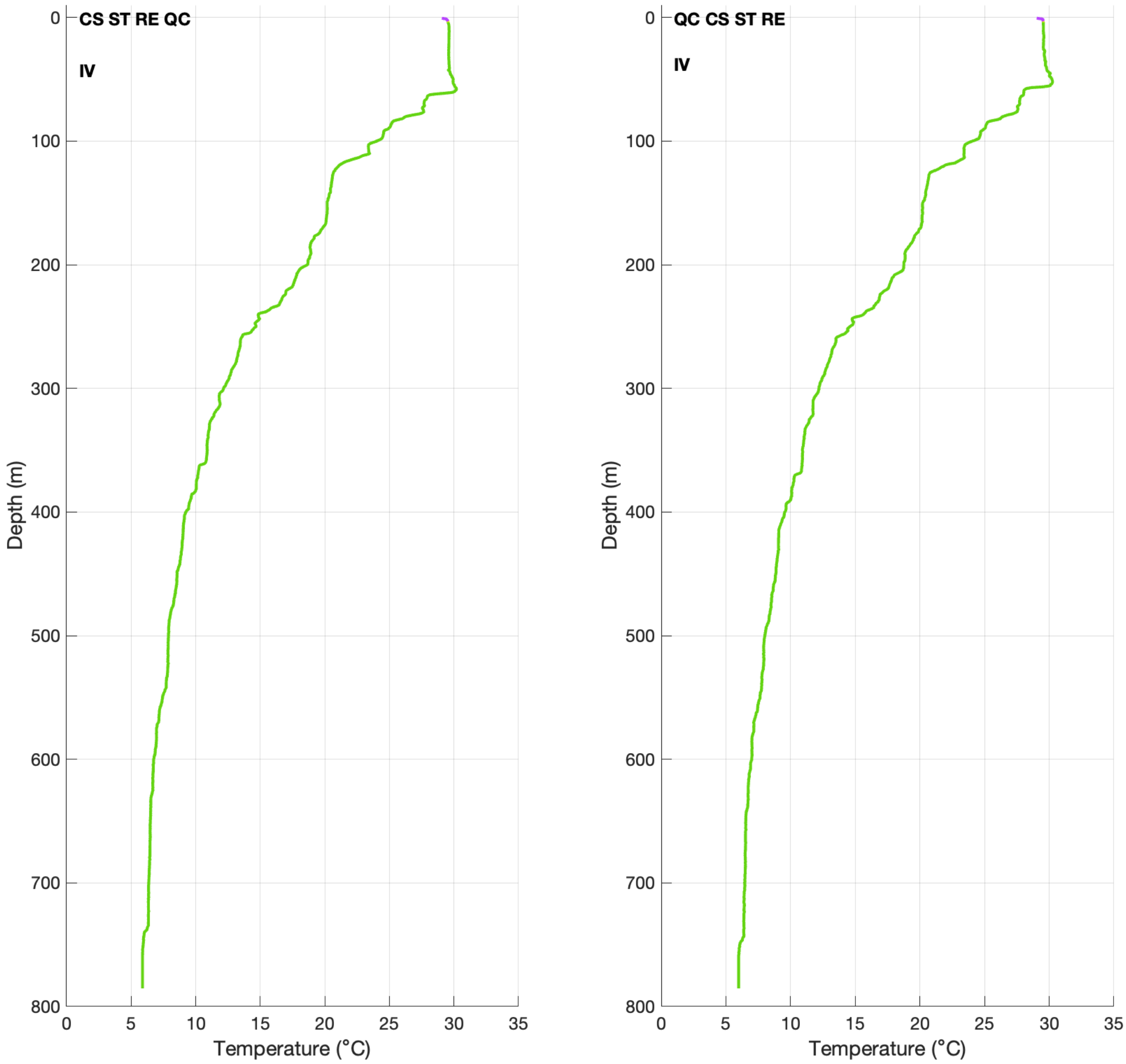
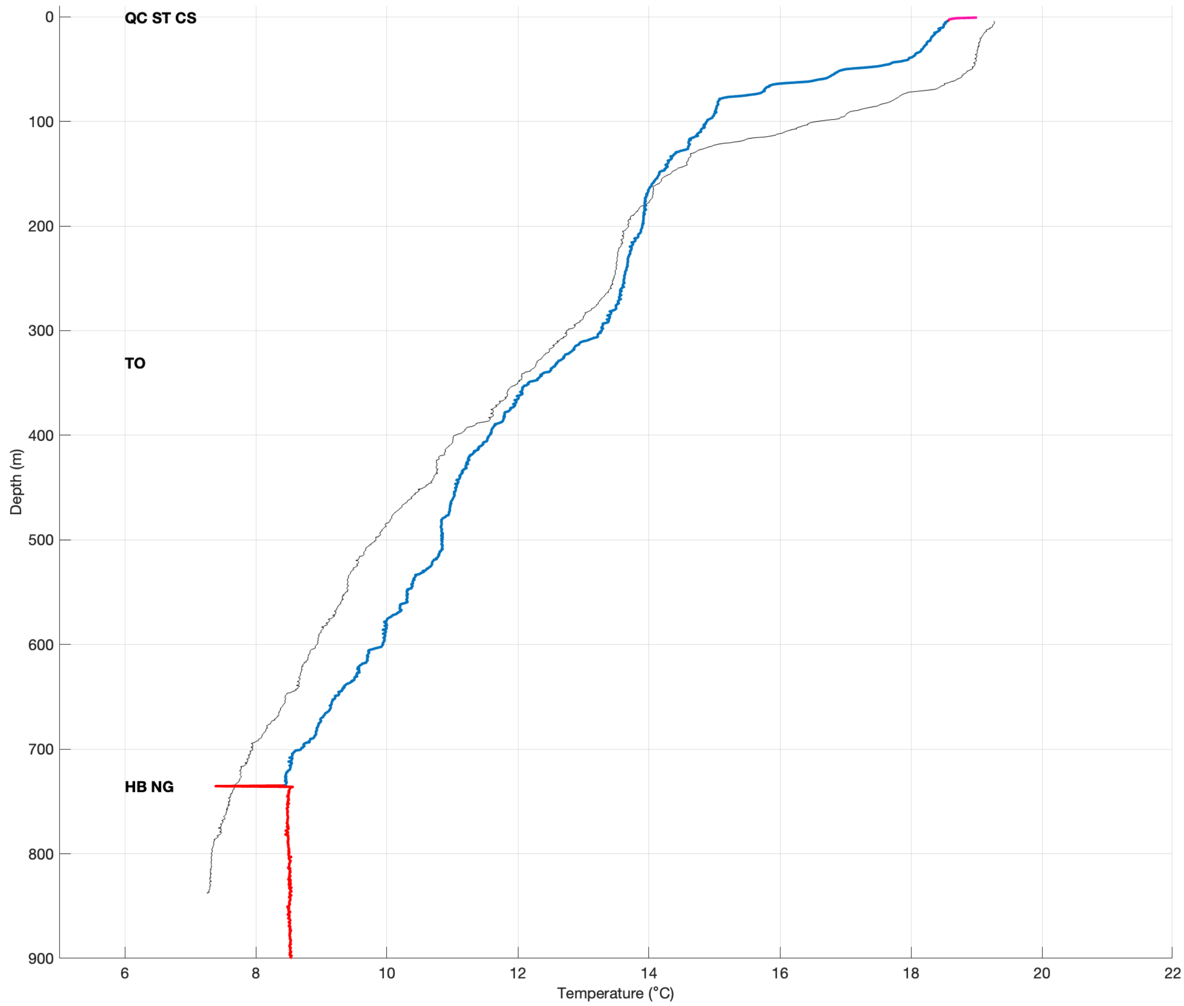


Figure 21. Probable Step-Like Structure example ST accept (GTSPP flag 2, blue), with no confirmation from neighbouring profiles.



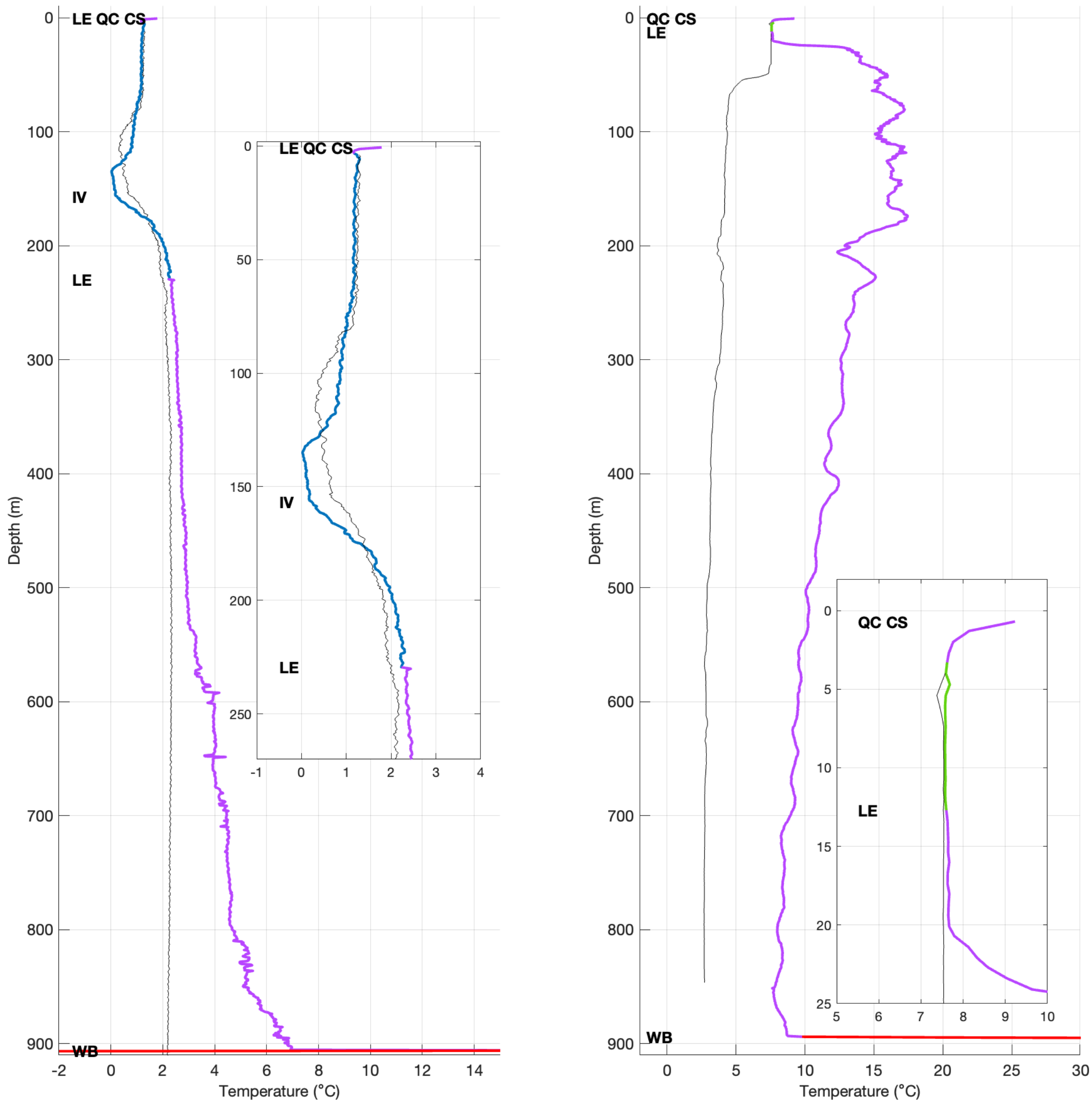
4.6.2 Leakage (LE)

Leakage occurs due to a signal leakage problem with the recording equipment (Figure 22). Leakage appears as "jitter" over a range of depths (or the entire profile). LE can be used if there is doubt about whether the XBT system is working correctly. Leakage can also be a result of insulation penetration (EI) which has not healed leading to continuous leakage, or damage to the launcher cable or recorder.

GTSPP flag 2 is applied to temperature data where the magnitude of the anomaly is small (~0.2°C over a range of depths) and does not seriously affect the overall quality of the data. GTSPP flag 3 is applied to temperature data if leakage is observed as an erratic, sharp and unrealistic structure over a range of depths or the entire profile. Temperatures at depths below the first appearance of leakage are generally warmer than neighbouring profiles.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
LE Accept	At the first depth of leakage	2	1
LE Reject	At the first depth of leakage	3	1

Figure 22. Leakage examples (LE). LE accept from surface (GTSPP flag 2, blue) followed by LE reject (GTSPP flag 3, purple), left panel. Right panel shows an example of LE reject from approximately 15 m. Both panels show zoomed in regions where LE reject is applied. Neighbouring (good) profiles are shown in black.



4.7 Oceanic Features QC

Eddies, oceanic fronts and currents are common meso-scale features in the oceans. These often appear in profile data as distinct increases and/or decreases in the temperature over large depth ranges when compared to neighbouring profiles. Depending on the horizontal sampling interval, a series of temperature displacements with depth can sometimes be seen in alternating or sequential drops as the ship crosses an eddy, current system or frontal region. There are XBT probe or system malfunctions which can resemble these real features. An indication that the XBT may have malfunctioned due to wire stretch (WS), leakage (LE) or a probe defect (eg, TO) is often an observed temperature difference (>0.2°C) at the bottom of the temperature profile when compared with repeats or neighbours. Care must be taken to distinguish between such temperature offsets due to instrument malfunctions and ones due to real meso-scale features in the ocean. This is particularly true if the XBT does not sample to the bottom of the thermocline or if sampling is not at intervals that will resolve the horizontal space scales of the eddies, currents or fronts.

Table 7. Eddy-Front and Temperature Offset codes

QC code label	Code	Use Description	GTSPP Flag	
			Temperature	Depth
Eddy/Front	**EF Accept**	If repeat or neighbouring profile pairs each side of the front show offsets in shallower regions, and similar temperatures at depth.	1 from the surface	1
Temperature offset or Surface Anomaly	**TO Accept**	If a temperature differences (>0.2°C) is observed when compared to neighbouring profiles and this difference cannot be confirmed with repeat or neighbouring profiles. Eddies or fronts can be seen in historical observations in the region. In the case of a surface anomaly, the remainder of the profile agrees with neighbouring profiles.	2 from the depth of the temperature offset	1
	TO Reject	If temperature differences cannot be confirmed by a neighbouring drop and there is limited evidence that eddies or fronts occur in the region. In the case of a surface anomaly, the remainder of the profile does not agree with neighbouring profiles.	3 from depth of the temperature offset	1

4.7.1 Eddy / Front / Current (EF)

An eddy, front or current is observed as a temperature offset over large depth ranges. Eddy fronts or currents can best be diagnosed by review of 4 sequential drops in a ship track. There will appear an offset in temperature at depth between profiles 2 and 3. Profiles 1 and 2 temperatures should agree at depth. Profiles 3 and 4 temperatures should agree at depth.

The depth of the eddy front or current can be varied. Differences may occur near the surface, in the middle part, or at depth. Two consecutive profiles can have an offset over the entire depth range. Figures 23 to 25 give three examples of EF application.

The EF code is applied from the surface, to the two neighbouring profiles with largest offset in temperature in the shallower regions.

Code	Depth of application	GTSPP Quality flag	
		Temperature	Depth
EF Accept	At the surface	1	1

Figure 23. Eddy Front example 1 (EF). Both panels show the same four consecutive (neighbouring) profiles performed during a transit across an eddy front. The two consecutive profiles coded with EF accept (GTSPP flag 1, green) are coloured in each panel. Temperatures are different between two groups for the entire depth as the ship crosses an eddy front.

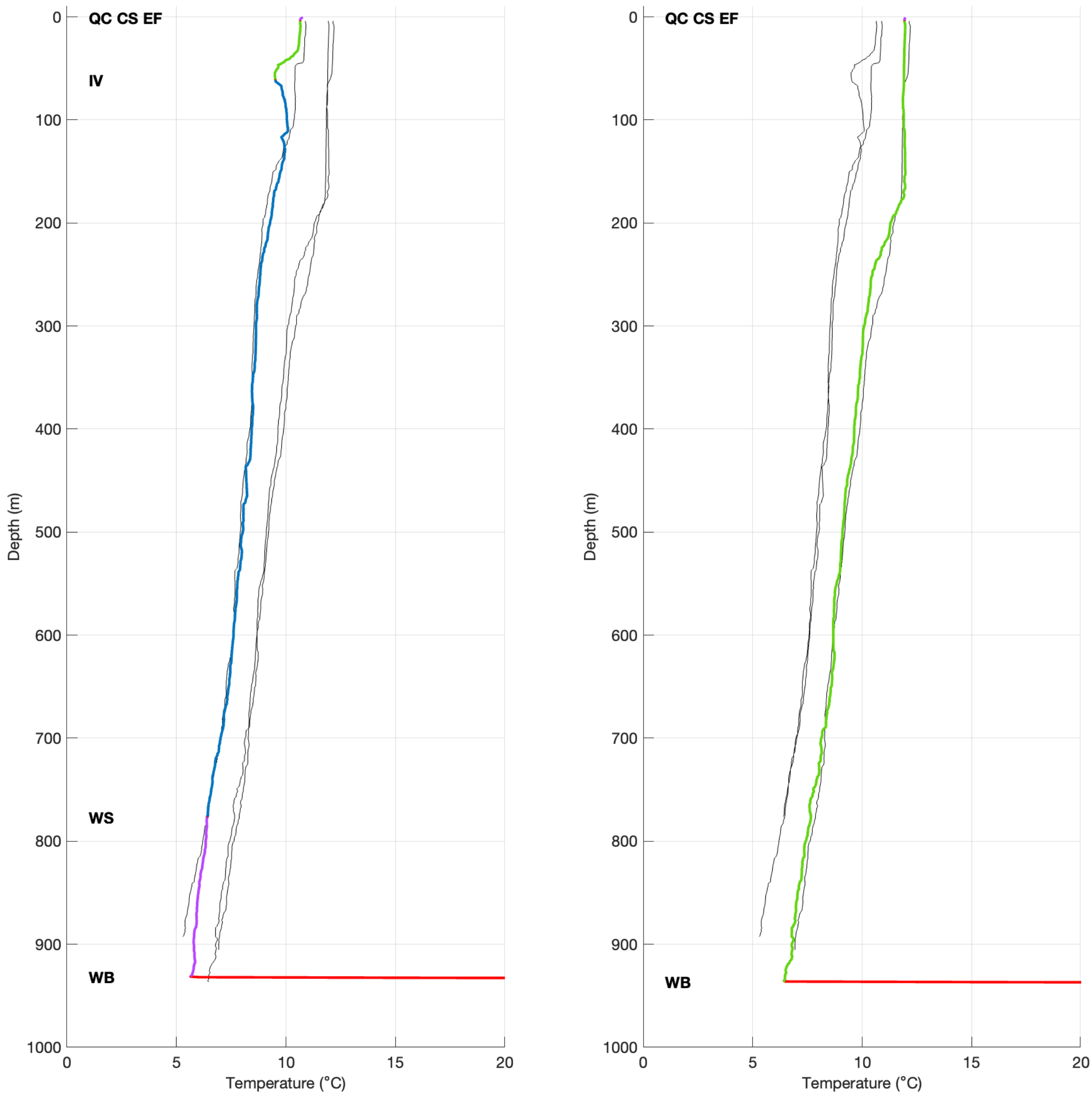


Figure 24. Eddy Front example 2 (EF). As for figure 22, but with profile temperatures showing similarities with neighbouring profiles at depth and large differences in the middle.

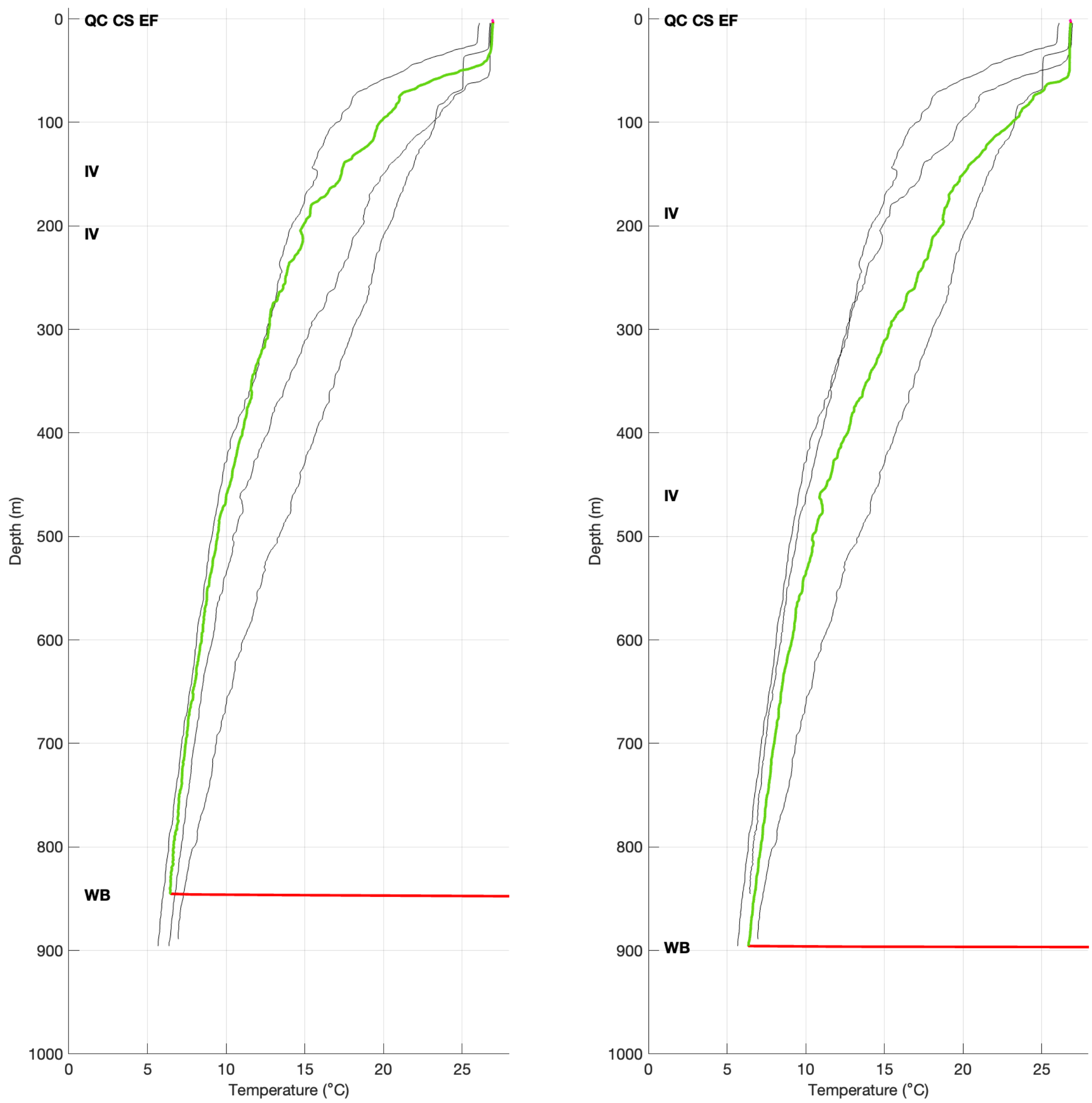
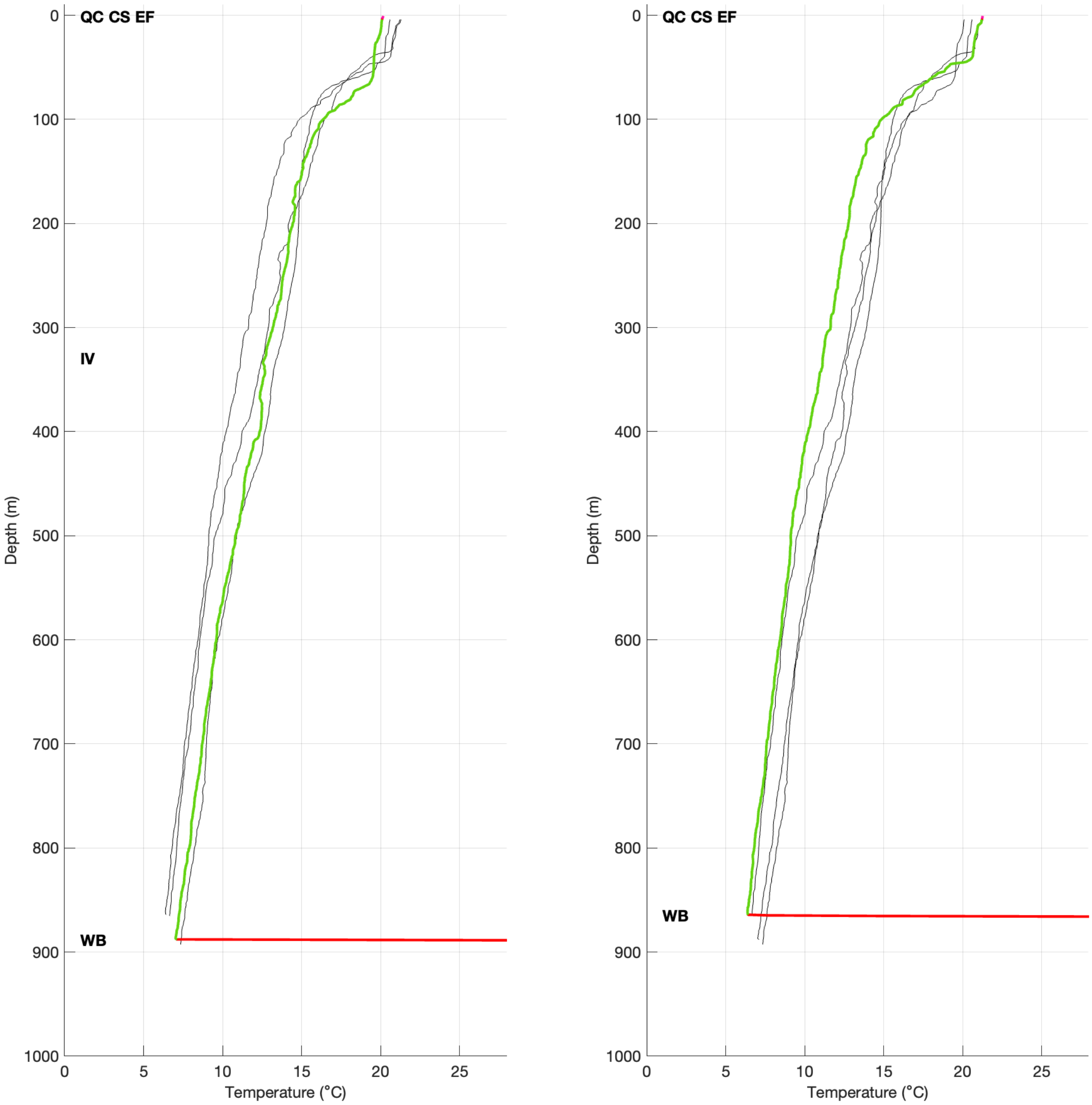


Figure 25. Eddy Front example 3 (EF). As for figure 22, with profile temperatures showing two groupings of temperatures at depth and similar temperatures above 400m.



4.7.2 Temperature Offset and Surface Anomaly (TO)

An offset in temperature at depth is observed when compared to neighbouring profiles. The temperature difference can occur over the entire profile, but the defining feature is the offset at the bottom of the profile. The feature is probably real as eddies, fronts or currents are known to occur in the region, although there is no confirmation from repeat or neighbouring profiles.

Temperature offsets can also be seen as a surface anomaly. A warm surface layer can sometimes form from solar heating and light winds (often referred to as the afternoon effect). The afternoon effect can warm surface layers of between 2-10 m thick by up to 1°C. Cooler freshwater layers due to precipitation or river-outflow can also cause a surface anomaly to develop. A surface anomaly is generally > 0.2°C. These surface features can have small spatial scales that can be confused with XBT-specific surface transients (CS). Figures 26 and 27 show examples of TO application.

TO Accept is applied to profiles where temperature differences (>0.2°C) are observed when compared to neighbouring profiles. TO Reject is applied to temperature data if the temperature difference cannot be confirmed by a neighbouring drop and there is limited evidence that eddies or fronts occur in the region. In the case of a surface anomaly, the remainder of the profile does not agree with neighbouring profiles.

<table>
<tr><th rowspan="2">Code</th><th rowspan="2">Depth of application</th><th colspan="2">GTSPP Quality flag</th></tr>
<tr><th>Temperature</th><th>Depth</th></tr>
<tr><td>TO Accept</td><td>At the depth of the offset or anomaly</td><td>2</td><td>1</td></tr>
<tr><td>TO Reject</td><td>At the depth of the offset or anomaly</td><td>3</td><td>1</td></tr>
</table>

Figure 26. Temperature Offset examples (TO). TO accept (GTSPP flag 2, blue), left panel. TO reject (GTSPP flag 3, purple), right panel. Neighbouring profiles are shown in black.

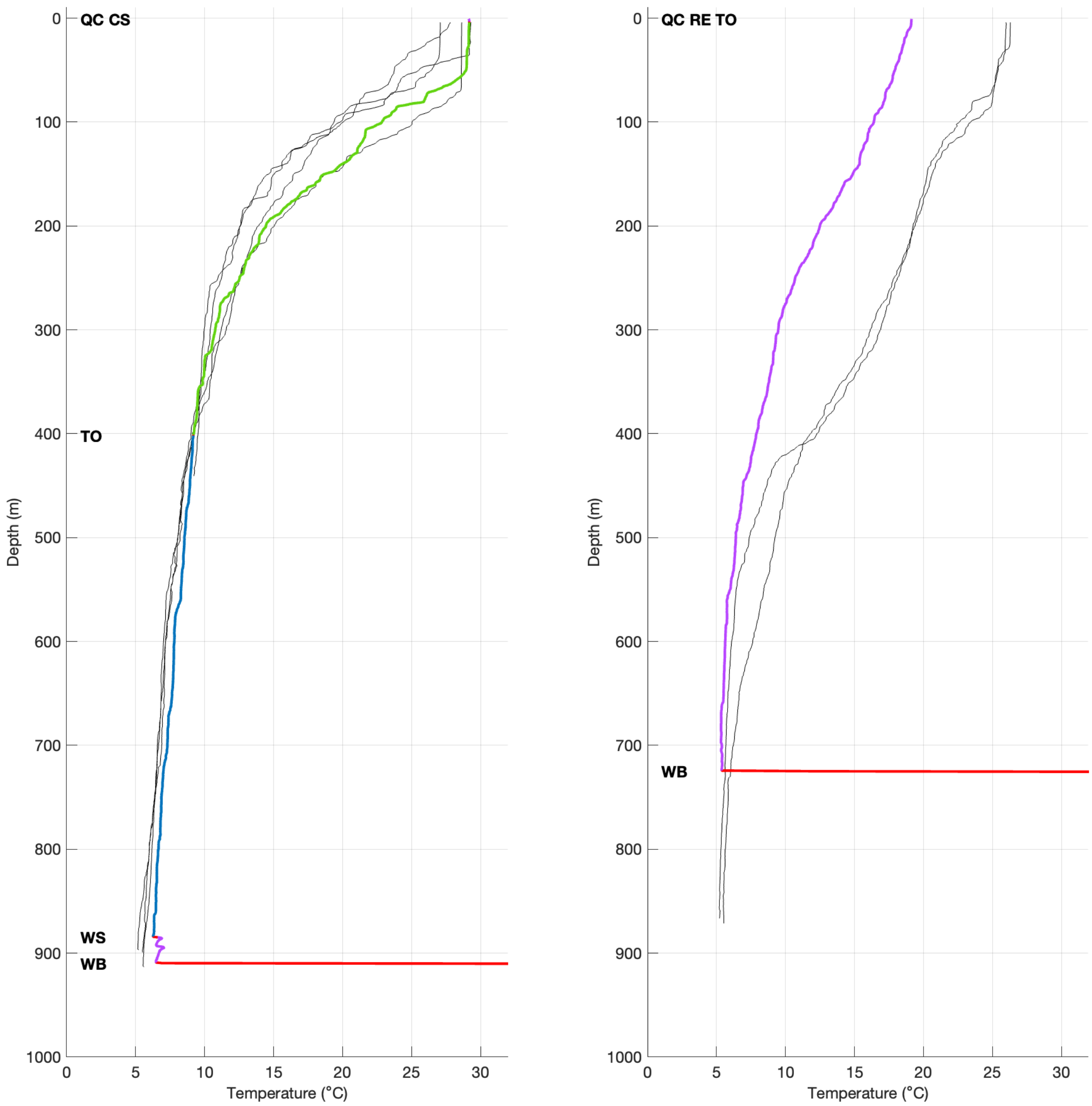
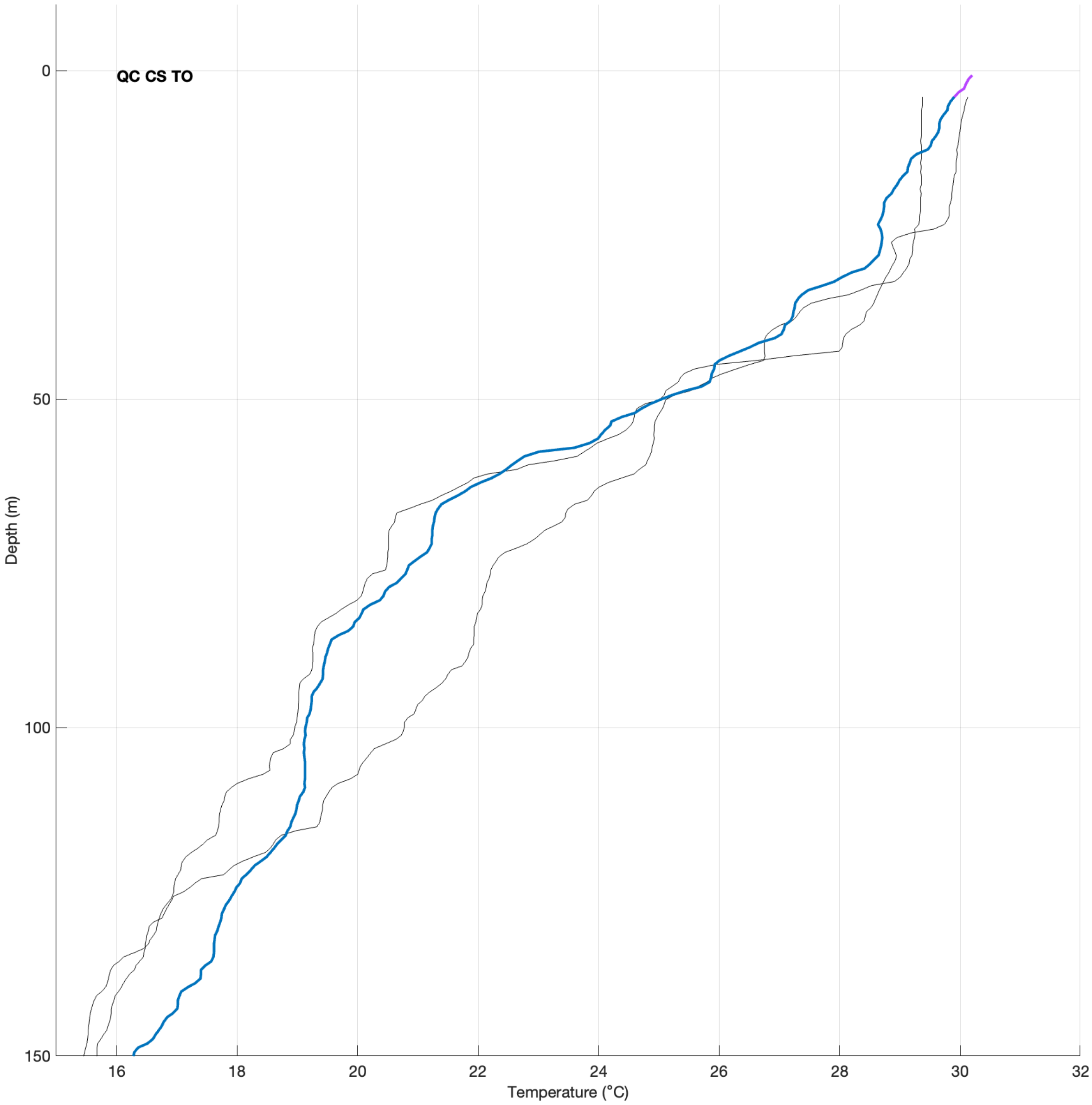


Figure 27. Surface Anomaly example (TO) (GTSPP flag 2, blue). In this example, the surface to ~25m depth demonstrates a cooling compared to neighbouring profiles (black), but the remainder of the profile is consistent with neighbours.



4.8 Historical QC codes no longer used

Table 8 lists QC codes that are fully described in Bailey et al (1994) but are no longer in routine use in Australian Quality control processes. When quality controlling historical data, some of these codes, particularly those with recording system errors, will be of use. Data quality controlled prior to 2023 will contain some of these codes.

Table 8. List of codes in Bailey et al (1994) that are no longer in use.

QC code label	Code	Use Description	GTSPP Quality Flag for Temperature	Equivalent QC code in this document (Version 2.0)
Bathy Systems Software Fault (Modulo 10 Spikes)	**MO Accept**	Used when regular spiking (modulo 10 spikes) is seen in a profile that has been recorded with a BathySystems SA-810 system. Spikes are interpolated over.	2 from the surface	None
	MO Reject	Used when >0.2°C spiking (modulo 10 spikes) is seen in a profile that has been recorded with a BathySystems SA-810 system. Spikes cannot be successfully interpolated over.	3 from the surface	None
Surface Transients	**CS Accept**	Accounts for surface startup transients from the surface up to and including 3.6 m depth.	3 at each depth up to and including 3.6 m	CS Reject
PROTECNO Systems Leakage (PET Fault)	**PF Accept**	Used to identify the suspected start of PROTECNO System leakage fault where the start of leakage cannot be identified clearly when comparing with neighbouring profiles.	2 from depth of anomaly	None
	PF Reject	Used if leakage occurs in a profile that has been recorded with a PROTECNO System.	3 from depth of PET fault	None

QC code label	Code	Use Description	GTSPP Quality Flag for Temperature	Equivalent QC code in this document (Version 2.0)
Bathy Systems Leakage (Cusping)	**CU Accept**	Used if <0.2°C periodic cusping from the BathySystems SA-810 unit is identified and the error does not impact on the overall profile quality.	2 from depth of cusping	None
	CU Reject	Used if >0.2°C periodic cusping from the BathySystems SA-810 unit is identified and the error degrades the overall profile quality.	3 from depth of cusping	None
Bathy Systems Bowing (Bowed Mixed Layer)	**BO Accept**	Used if a warming (‘bowing’) of <0.02°C is identified in the mixed layer of a profile collected using BathySystems SA-810 recorders, indicating that the inversion may be real for the region.	2 from the surface	None
	BO Reject	Used if a warming (‘bowing’) of >0.02°C is identified in the mixed layer of a profile collected using BathySystems SA-810 recorders in a region where inversions have not been recorded.	3 from the surface	None
Sippican MK-9 Processor Malfunction (Sticking Bit Problem)	**SB Accept**	Used if small amplitude step-like features are observed in a profile recorded with a particular version of the Sippican MK-9 unit. Apply a 19-point filter with coefficients of 0.0562.	2 from the surface	None
	SB Reject	Used if large amplitude step-like features are observed in a profile recorded with a particular version of the Sippican MK-9 unit.	3 from the surface	None

QC code label	Code	Use Description	GTSPP Quality Flag for Temperature	Equivalent QC code in this document (Version 2.0)
Sippican MK-9 Timing Delay Problem (Driver Error)	**DR Accept**	Used on ALL profiles recorded with specific versions of the Sippican MK-9/MS-DOS XBT system. Data is corrected by adding the number of meters corresponding to the mode of the timing delay (2.6s) as calculated by bench tests of the relevant equipment. A further 4 meters of data is deleted due to start up transients, taking the total depth of affected data to 20m.	2 from the surface	None
	DR Reject	Used on profiles recorded with specific versions of the Sippican MK-9/MS-DOS XBT system that exhibit extreme inconsistencies that cannot be corrected. No correction applied.	3 from the surface	None
No Trace	**NT Reject**	No temperature data recorded or temperature data are off-scale.	4 from the surface	WB Reject or NG Reject
Hit Bottom Accept	**HB Accept**	Indicate the depth of possible bottom hit location.	2 from depth of possible isothermal boundary layer	HB Reject
Spike	**SP Accept**	Spike(s) occur at one or more depths and do not impact on the deeper temperature data. The temperatures at SPA depths are replaced with interpolated temperatures.	2 from depth of spike	EI Accept

QC code label	Code	Use Description	GTSPP Quality Flag for Temperature	Equivalent QC code in this document (Version 2.0)
	SP Reject	Spike(s) occur at one or more depths and impact on the deeper temperature data in the profile.	4 from depth of spike	EI Reject
Inversion in mixed layer	**NU Accept**	Confirm nub (warming in surface layer) with neighbouring profiles and repeat drops.	1 from depth of inversion	IV Accept flag 1
Inversion (Probable)	**PI Accept**	No confirmation of inversion (warming) in neighbouring profiles, but the area is known for inversions and/or inversions are seen in historical profiles.	2 from depth of probable inversion	IV Accept flag 2
Surface Anomaly	**SA Accept**	Used if a cool anomaly (of > 0.2°C) is detected in the top 20 metres of the water column and the remaining profile agrees with repeats or neighbours.	2 from the surface	TO Accept
Fine structure (probable)	**FS Accept**	Used if the fine-scale structure cannot be completely confirmed by a repeat or neighbouring profile, but similar features have previously been observed in the region.	2 from the surface	ST Accept flag 2
Fine Step-like structure (probable)	**PS Accept**	Used if structured step-like features are observed in a profile but cannot be completely confirmed by a repeat or neighbouring profile, but similar features have previously been observed in the region.	2 from the surface	ST Accept flag 2
Insulation Penetration	**IP Accept**	Insulation penetration(s) occur at one or more depths and do not impact on deeper temperature data in the profile. The	2 from depth of failure	EI Accept

QC code label	Code	Use Description	GTSPP Quality Flag for Temperature	Equivalent QC code in this document (Version 2.0)
		temperatures at IPA depths are replaced with linearly interpolated temperatures.		
	IP Reject	Insulation penetration(s) occur at one or more depths and impact on the deeper temperature data in the profile.	3 from depth of failure	EI Reject

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Appendix A Complete list of QC codes used by Australian agencies

This section summarises the QC codes that appear in historical lists used to QC XBT, MBT, CTD and bottle data types. Some codes are missing explanations, but we will endeavour to continue to find explanations where possible. Green shading indicates automated QC codes applied during the IOTA (Indian Ocean Thermal data Assembly) and QuOTA (Quality controlled Ocean Temperature Archive) process (Gronell and Wijffels, 2008), and yellow indicates missing or best guesses of descriptions.

The third column, 'depth source', refers to the method used in the Mquest QC GUI to apply the code.

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
BBA	1	0	Bad bottle data - insert missing value at cursor
BDA	1	0	Bathy data accept – Low resolution data
BDR	3	0	Bathy data reject – Low resolution data
BOA	2	0	Bowing, BathySystems
BOR	3	0	Bowing, BathySystems
BTA	2	1	IOTA Automated QC code: Bottle Code Integrated Binned T
BTR	2	1	IOTA Automated QC code: Bottle Code Integrated Binned T, reject
CLR	3	1	contact lost with probe - reject
CSA	5	0	Surface data transients up to and including 3.6m
CSR	3	0	Surface data transients reject
CTA	1	0	Constant temperature in surface layer, flag 1 to 10m
CTR	3	1	Constant temperature reject from 10m if CTA is applied
CUA	2	1	Cusping, BathySystems leakage

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
CUR	3	1	Cusping, BathySystems leakage
DAA	0	0	Unknown
DCA			Depth corrected (new equation, presumably Hanawa 1995 equation)
DDA	2	1	IOTA Automated QC code: DTDZ
DDR	3	0	NOT USED?
DEA	2	0	Depth error accept. Multiply depth by 10m. Used for 'JDRD' dataset
DOR	3	0	Depth offset reject (probably used for Sippican Mk9 or early systems)
DPA	0	0	Depth corrected, fall rate equation updated. No calculation done in Mquest.
DRA	2	0	Sippican MK9 timing delay driver error
DRR	3	0	Sippican MK9 timing delay driver error
DTA	2	0	Data type corrected (eg XBT to CTD?)
DUA	0	0	Duplicate drop, non-identical (might be different depth resolution)
DUR	3	0	Duplicate drop, identical to another in archive
DZA	2	1	IOTA Automated QC code: Temperature gradient over the temperature bin boundaries
DZR	2	1	NOT USED
EEA	2	0	Unknown
EFA	1	0	Eddy front
ERA	2	0	Early recording error, probe not in water

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
FSA	2	0	Fine structure (probable)
FSR	3	0	NOT USED
GLA	2	1	IOTA Automated QC code: Long gradient
GLR	3	2	NOT USED
GRR	3	1	Gradient reject – used for early systems and probably low resolution data.
GSA	2	1	IOTA Automated QC code: Short gradient
GSR	3	2	NOT USED
HBA	2	1	Hit bottom accept
HBR	3	1	Hit bottom reject
HFA	2	1	High frequency filter applied, temperature values replaced
HFR	3	1	High frequency reject
IDA	2	0	Unique ID number changed, store original ID
IPA	2	1	Insulation penetration
IPR	3	1	Insulation penetration
IVA	1	1	Inversion
LEA	2	0	Leakage
LER	3	1	Leakage
M1A	2	1	IOTA Automated QC code: Depth where the temperature is more than 0.5degrees cooler than the SST
M1R	3	1	NOT USED

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
M2A	2	1	IOTA Automated QC code: Depth where the gradient change (absolute change of temperature/change of depth) is greater than 0.25.
M2R	3	1	NOT USED
MBR	3	1	Mechanical bathythermograph data, reject due to the data looking incorrect.
MLA	1	0	Mixed layer
MLR	3	1	Mixed layer
MOA	2	1	BathySystem software fault, modulo 10 spikes, replaced with filtered data (Flags.txt - spike replaced with linearly interpolated values)
MOR	3	0	BathySystem software fault, modulo 10 spikes, reject data below
MSA	2	0	Unknown
NAA	1	0	IOTA Automated QC code: Not assessed - not enough data in the region
NAR	1	0	NOT USED
NGR	4	1	No good
NTR	4	0	No trace
NUA	1	1	Nub (inversion at bottom of mixed layer)
OPA	2	0	Other Probe type error - eg T7 vs DB
OPR	3	1	Other Probe type error - but unknown
PEA	2	0	Position error
PEH	2	0	Position error correct hemisphere

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
PER	3	0	Position error
PFA	2	1	Protectno systems leakage (PET fault)
PFR	3	1	Protectno systems leakage (PET fault)
PIA	2	1	Probable inversion
PLA	2	0	Premature launch, move temperatures up to surface from point of cursor
PSA	2	0	Probable fine step-like structure
QCA	1	0	Quality control applied by visual inspection
QUR			Questionable. Allows retrieval for later examination
REA	0	0	Repeat drop within 15 minutes of another drop
RER			Repeat drop rejected for other reasons
RTA	2	1	IOTA Automated QC code: Averaged integrated raw temperature.
RTR	2	1	NOT USED
SAA	2	0	Surface temperature anomaly
SAR	3	0	Surface temperature anomaly
SBA	2	0	Sippican MK9 processor malfunction, sticking bit problem (data replaced with 19 POINT FILTER WITH COEFF 0.0526}
SBR	3	0	Sippican MK9 processor malfunction, sticking bit problem, reject below
SFA	1	0	Surface feature accept
SFR	3	0	Surface feature reject

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
SOA	2	0	Surface temperature offset questionable
SOR	3	0	Surface temperature offset reject
SPA	2	1	Spike interpolated and value replaced
SPR	4	1	Spike reject data below
STA	1	0	Confirmed step-like structure
T1A	2	1	IOTA Automated QC code: Temperature at 100m.
T1R	2	1	NOT USED
T2A	2	1	IOTA Automated QC code: Temperature at 250m.
T2R	2	1	NOT USED
TAA	2	1	Temperature anomaly accept
TDA	2	1	Temperature difference at depth
TEA	2	0	Time error, time replaced
TER	3	0	Time error reject entire profile
TGA	2	0	Temperature gradient accept – early systems
TGR	3	0	Temperature gradient reject – early systems
TIA	2	0	Temperature inversion accept – early systems
TIR	3	0	Temperature inversion reject – early systems
TOA	2	1	Temperature offset from neighbours
TOR	3	1	Temperature offset from neighbours
TPR	4	0	Test probe do not include in archive

Code (A = Accept, R = Reject)	GTSPP Flag	depth source (0=NA;1=depth from menu;2=depth from cursor)	Description
TVA	2	1	IOTA Automated QC code: Cumulative Integrated raw temperature
TVR	2	1	NOT USED
TZA	2	1	IOTA Automated QC code: Temperature of a depth surface.
TZR	2	1	NOT USED
URA	2	0	Under resolved profile, surface interpolations probably garbage
URR	3	1	Under resolved profile, surface interpolations probably garbage, reject
WBR	4	1	Wire break reject
WSA	2	1	Wire stretch accept
WSR	3	1	Wire stretch reject
ZTA	2	1	IOTA Automated QC code: Depth of a temperature surface.
ZTR	2	1	NOT USED

Appendix B Integer codes and Quality control codes

This table of integer codes used to identify the Quality Control codes was used early in the history of XBT data collection. During the early 1980's to mid 1990's, file sizes were extremely limited, and in place of a character code, a single integer was used to identify a code. These codes are included in the document as a historical record and are no longer in use.

Table of integer codes used to identify the Quality Control codes

CATEGORY	ACCEPT FEATURE CHARCTER CODE	INTEGER CODE	REJECT FEATURE CHARACTER CODE	INTEGER CODE
Surface Spikes	CSA	1		
Modulo 10 Spikes	MOA	2	MOR	-2
Wire Break			WBR	-3
Hit Bottom	HBA	4	HBR	-4
PROTECHNO Leakage	PFA	5	PFR	-5
Inversion	IVA	6		
Nub	NUA	7		
Fine Structure	STA	8		
Wire Stretch	WSA	9	WSR	-9
Leakage	LEA	10	LER	-10
Bathy System Leakage (cusping)	CUA	11	CUR	-11
High Frequency Noise	HFA	12	HFR	-12
Insulation Penetration	IPA	13	IPR	-13
Spikes	SPA	14	SPR	-14
Bathy Systems Bowing	BOA	15	BOR	-15
Surface Anomaly	SAA	16		
Temperature Difference at Depth	TDA	17		
Temperature Offset			TOR	-17

CATEGORY	ACCEPT FEATURE CHARCTER CODE	INTEGER CODE	REJECT FEATURE CHARACTER CODE	INTEGER CODE
Constant Temperature	CTA	18	CTR	-18
No Trace			NTR	-19
No Good			NGR	-20
Test Probe			TPR	-21
Repeat Drop	REA	24	RER	-24
Sippican MK-9 processor error (sticking bit)	SBA	27	SBR	-27
Other / Probe Error	OPA	28	OPR	-28
Fine Structure	PSA	29		
Sippican MK-9 Timing Delay	DRA	30	DRR	-30
Probable Inversion	PIA	31		
Eddy / Front	EFA	32		
Position error	PEA	33	PER	-33
Time / Date Error	TEA	34	TER	-34
Duplicate Drop	DUA	35	DUR	-35
Quality Control	QCA	36		
Probable Step-like Fine Structure	PSA	37		

Appendix C MQuest key shortcuts

A summary of the MQuest GUI shortcut keys useful in entering QC and moving within a data set

key	**description/action**
esc	exit program after saving any QC
f1	apply QCA code
f2	show QC
f3	delete QC
f4	'kill' profile (replace with unedited, raw data)
f5	set buddies to +/- 1 profile
f6	set buddies to +/- 1 profile
f7	set buddy region to +/- 0.5 deg
f8	set buddy region to +/- 1.0 deg
f9	display only 10 buddies from the current selection
f10	set buddy region to +/- 0.1 deg
f11	show good buddy data only
f12	show all buddy data including rejected data
delete	zoom map focussed on the current profiles position
insert	return map to original axes
page down	profile display
page up	buddy display
left arrow	zoom profile
right arrow	reset zoom to original axes
up arrow	go to next profile
down arrow	go to previous profile
home	go to drop 1
numpad1	set buddies for only one year - display buddy profiles only if they are from the same year as the current profile
numpad2	set buddies for all years - display all buddies, regardless of year
numpad3	set buddies to +/- 0.25 deg
numpad5	set buddies to +/- 1.5 deg
numpad6	set buddies to +/- 4 deg
numpad9	set buddies to +/- 3 deg
multiply	(number pad *) - set temp scale to show surface values that are off-scale
subtract	(number pad -) - set window to show entire trace -used to see bottom of deep traces

These require a leading 'q' key

key	code	description (see Cookbook for detailed descriptions)
1	SPA	%spikes - SPA - chop only one point!
2	TOR	%temperature offset - reject from the surface SEE ALSO STANDALONE "O" KEY
3	TPR	%test probe - reject from the surface
5	HFA	%high frequency filter THE ENTIRE TRACE SEE ALSO STANDALONE "H" KEY
w	WSA	%wire stretch
e	EFA	%eddy-front region
r	REA	%repeat profile (within 15 minutes)
t	TOR	%TOR from cursor SEE ALSO STANDALONE "O" KEY
y	BBA	%bad bathy (replace with missing value)
u	URA	%under resolved profile
i	IVA	%inversion - confirmed
o	TOA	%temperature offset - accept!!! %reject from cursor
p	PIA	%probable inversion
left bracket	CTA	%constant temperature - accept to 10m and reject below
right bracket	STA	%steps - confirmed
backslash	NON	%not used
a	NON	%not used
s	SAA	%surface anomaly
d	DUR	%duplicate profile - reject
f	FSA	%fine structure
g	NON	%not used
h	HFA	%high frequency noise - filter from the current cursor point to the bottom of the trace SEE ALSO STANDALONE "H" KEY
j	PSA	%probable steps
k	LER	%leakage - reject from cursor position
l	LEA	%leakage - accept and flag from the surface
z	HBR	%hit bottom SEE ALSO STANDALONE "Z" KEY
x	NGR	%no good - reject from cursor
c	CSA	%chop surface spikes
v	IPR	%insulation penetration - reject from cursor SEE ALSO STANDALONE "V" KEY
b	WBR	%wire break - reject from cursor SEE ALSO STANDALONE "B" KEY
n	NUA	%nub
comma	IPA	%insulation penetration - interpolate over spike (launches GUI so you can select the end point of the interpolation. The start point is the current cursor position).
period	SPA	%spikes - interpolate over spike(s) (launches the GUI described above for IPA).

The following keys are stand-alone - they are used WITHOUT the leading 'q' key

key description (see Cookbook for detailed descriptions)

3 %HBA - Hit bottom - automatically puts on HBA at current cursor position - make sure you pick this from the depth/temperature list.
4 %display buddies +/1 2.0 degrees latitude and longitude
5 %get rid of duplicate history records...
6 %get cursor position from map and retrieve profiles from coordinates
7 %set buddies for only one year - display buddy profiles only if they are from the same year as the current profile
8 % buddies for all years - display all buddies, regardless of year
9 %remove ALL Quest QC flags - not active because dangerous - can easily be restored if required.
0 %redraw map window...
b %add WBR automatically
c %add CSA and QCA, and display buddy profiles
d %DUR profile, save, and send to the next profile
f %add FSA, CSA and QCA codes and display buddy profiles
h %HFA the entire profile from the surface
j %add PSA, CSA and QCA codes and display buddy profiles
k %add LER at surface
o %TOR entire profile
p %change position (latitude or longitude) - new position is entered via GUI
t %TEA - change date and/or time - new date and time are entered into a GUI
v %add IPV from the surface
z %add HBR and NGR automatically at the selected depth - removes any HBR or NGR already present

Appendix D Spike and Insulation Penetration interpolation algorithm

The following is a code snippet taken from the MQuest GUI used for QC of XBT data. The snippet completes the interpolation of XBT temperature data containing spikes or insulation penetrations and described in the section on Electrical Interference (EI).

```
%interpolate spikes for spikes and insulation penetrations using Matlab coding.
%startpoint is the depth at which the cursor is in the GUI window. endpoint is the final depth to apply the SP interpolation
to, selected by the user when choosing the code

dd = [pd.depth(startpoint-1) pd.depth(endpoint+1)];
pt = [pd.temp(startpoint-1) pd.temp(endpoint+1)];
pd.temp(startpoint:endpoint) = interp1(dd,pt,pd.depth(startpoint:endpoint));
```

Appendix E High Frequency filtering algorithm

The following is a code snippet taken from the MQuest GUI used for QC of XBT data. The snippet completes the filtering of XBT data containing high frequency noise and described in the section on Electrical Interference (EI).

```
% medianfilter
%takes a temperature profile exhibiting high frequency noise and filters it
%using a median filter of 25 points to smooth the data.

filttemp=pd.temp; %temperatures
temptemp=filttemp;
%startpoint is the depth at which the cursor is in the GUI window. endpoint is the final depth to apply the HF filter to,
selected by the user when choosing the code
s1=min(startpoint,endpoint);
s2=max(startpoint,endpoint);

for kk=s1:s2
  if(kk-25<1)
    start=1;
  else
    start=kk-25;
  end
  % pd.ndep are the depths
  if(kk+25>pd.ndep)
    endjj=pd.ndep;
  else
    endjj=kk+25;
  end
  tt=filttemp(start:endjj);
  llk=find(tt<99);
  if(~isempty(llk))
    temptemp(kk)=median(tt(llk));
  else
%retain original value
  end
end

pd.temp=temptemp;
```

Appendix F Examples of QC code and GTSPP flag representation in XBT data files.

Following are some examples of how GTSPP flags and QC codes may be represented in different file formats. The MedsAscii format is unlikely to change, but the netCDF examples could be different in future file formats.

Sample 1. MedsAscii text format.

Text file in 'MedsAscii' format (*.MA). Yellow highlights show the QC codes applied to temperature and the depth of application. Green highlights show the GTSPP quality flags applied to each temperature data point.

```
00000100      NP3001    202112300735XB          U      -22.3984-166.161511120220203
CSXB    A 1 017  8 2TEMPN72999.2CSID89014009  1GCLL5BVZ4     0PEQ$052      0RCT$72       0OFFS-
5.1     0SCAL1.00016   0SER#1323407   0MFD#20190610  0HTL$28       0CRC$fea5cc1b  0TWI#PX30
0SHP#NordPacifi0VERS6.05.00   0FVRS6.0.03    0HVRS 5.3. 3   0SER1204      0UVRS9.2      0CSCSCB
2.020220203QCTEMP    0.67    27.374CSCSCB 2.020220203CSTEMP    0.67    27.374CSCSCB
2.020220203CSTEMP    1.34    27.387CSCSCB 2.020220203CSTEMP    2.01    27.395CSCSCB
2.020220203CSTEMP    2.68    27.397CSCSCB 2.020220203CSTEMP    3.34    27.393CSCSCB
2.020220203WSTEMP  819.58     5.472CSCSCB 2.020220203WBTEMP  913.83     6.885

00000101      NP3001    202112300735XB         TEMP 11500D  0.670   27.3743  1.340   27.3873
2.010   27.3953  2.680   27.3973  3.340   27.3933  4.010   27.3901  4.680   27.3901  5.350   27.3901
6.020   27.3881  6.690   27.3861  7.360   27.3651  8.030   27.3531  8.690   27.3371

...

6.6603911.410    6.6183912.010    6.5843912.620    6.5463913.220    6.5783913.830    6.8854914.430
8.9914915.030   36.2694915.640   36.2694916.240   36.2694916.850   36.2694917.450
36.2694918.060
```

Sample 2. NetCDF binary format.

Metadata GTSPP flags:

```
double TIME ;
    TIME:_FillValue = 999999. ;
    TIME:calendar = "gregorian" ;
    TIME:ancillary_variables = "TIME_quality_control" ;
    TIME:units = "days since 1950-01-01 00:00:00 UTC" ;
    TIME:axis = "T" ;
    TIME:standard_name = "time" ;
    TIME:long_name = "time" ;
    TIME:valid_min = 0. ;
```

```
        TIME:valid_max = 90000. ;
    byte TIME_quality_control ;
        TIME_quality_control:_FillValue = 99b ;
        TIME_quality_control:standard_name = "time status_flag" ;
        TIME_quality_control:quality_control_conventions = "IMOS standard flags" ;
        TIME_quality_control:long_name = "quality flags for time" ;
        TIME_quality_control:valid_min = 0b ;
        TIME_quality_control:valid_max = 9b ;
        TIME_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b ;
        TIME_quality_control:flag_meanings = "No_QC_performed Good_data Probably_good_data
Bad_data_that_are_potentially_correctable Bad_data Value_changed Not_used Not_used Not_used Missing_value" ;
    float LATITUDE ;
        LATITUDE:_FillValue = 999999.f ;
        LATITUDE:reference_datum = "geographical coordinates, WGS84 projection" ;
        LATITUDE:ancillary_variables = "LATITUDE_quality_control" ;
        LATITUDE:axis = "Y" ;
        LATITUDE:standard_name = "latitude" ;
        LATITUDE:long_name = "latitude" ;
        LATITUDE:units = "degrees_north" ;
        LATITUDE:valid_min = -90.f ;
        LATITUDE:valid_max = 90.f ;
    byte LATITUDE_quality_control ;
        LATITUDE_quality_control:_FillValue = 99b ;
        LATITUDE_quality_control:standard_name = "latitude status_flag" ;
        LATITUDE_quality_control:quality_control_conventions = "IMOS standard flags" ;
        LATITUDE_quality_control:long_name = "quality flags for latitude" ;
        LATITUDE_quality_control:valid_min = 0b ;
        LATITUDE_quality_control:valid_max = 9b ;
        LATITUDE_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b ;
        LATITUDE_quality_control:flag_meanings = "No_QC_performed Good_data Probably_good_data
Bad_data_that_are_potentially_correctable Bad_data Value_changed Not_used Not_used Not_used Missing_value" ;
    float LONGITUDE ;
        LONGITUDE:_FillValue = 999999.f ;
        LONGITUDE:reference_datum = "geographical coordinates, WGS84 projection" ;
        LONGITUDE:ancillary_variables = "LONGITUDE_quality_control" ;
        LONGITUDE:axis = "X" ;
        LONGITUDE:standard_name = "longitude" ;
        LONGITUDE:long_name = "longitude" ;
        LONGITUDE:units = "degrees_east" ;
        LONGITUDE:valid_min = -180.f ;
        LONGITUDE:valid_max = 180.f ;
    byte LONGITUDE_quality_control ;
        LONGITUDE_quality_control:_FillValue = 99b ;
        LONGITUDE_quality_control:standard_name = "longitude status_flag" ;
        LONGITUDE_quality_control:quality_control_conventions = "IMOS standard flags" ;
        LONGITUDE_quality_control:long_name = "quality flags for longitude" ;
        LONGITUDE_quality_control:valid_min = 0b ;
        LONGITUDE_quality_control:valid_max = 9b ;
        LONGITUDE_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b ;
        LONGITUDE_quality_control:flag_meanings = "No_QC_performed Good_data Probably_good_data
Bad_data_that_are_potentially_correctable Bad_data Value_changed Not_used Not_used Not_used Missing_value" ;
    string PROBE_TYPE ;
        PROBE_TYPE:_FillValue = 'Unknown' ;
        PROBE_TYPE:reference_datum = "WMO code table 1770" ;
        PROBE_TYPE:ancillary_variables = "PROBE_TYPE_quality_control" ;
        PROBE_TYPE:long_name = "XBT_probe_type" ;
        PROBE_TYPE:fall_rate_coefficients =  a:6.691,b:-0.00225;
```

```
            PROBE_TYPE:probe_type_name = "Sippican Deep Blue'" ;
        byte PROBE_TYPE_quality_control ;
                PROBE_TYPE_quality_control:_FillValue = 99b ;
                PROBE_TYPE_quality_control:long_name = "quality flags for PROBE_TYPE" ;
                PROBE_TYPE_quality_control:quality_control_conventions = "IMOS standard flags" ;
                PROBE_TYPE_quality_control:standard_name = "PROBE_TYPE status_flag" ;
                PROBE_TYPE_quality_control:valid_min = 0b ;
                PROBE_TYPE_quality_control:valid_max = 9b ;
                PROBE_TYPE_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b ;
                PROBE_TYPE_quality_control:flag_meanings = "No_QC_performed Good_data Probably_good_data Bad_data_that_are_p
  Not_used Not_used Not_used Missing_value" ;
        string PROBE_TYPE_RAW;
                PROBE_TYPE_RAW:_FillValue = 'Unknown';
                PROBE_TYPE_RAW:reference_datum = "WMO code table 1770" ;
                PROBE_TYPE_RAW:long_name = "PROBE_TYPE_original" ;
                PROBE_TYPE_RAW:fall_rate_coefficients =  a:6.691,b:-0.00225;
                PROBE_TYPE_RAW:probe_type_name = "Sippican Deep Blue'" ;

TIME = 25941.9020833333 ;
 TIME_quality_control = 1 ;
 LATITUDE = -7.04684 ;
 LATITUDE_quality_control = 1 ;
 LONGITUDE = 105.2052 ;
 LONGITUDE_quality_control = 1 ;
```

GTSPP quality flags for temperature:

```
      float TEMP(DEPTH) ;
            TEMP:_FillValue = 99.f ;
            TEMP:standard_name = "sea_water_temperature" ;
            TEMP:valid_min = -2.5f ;
            TEMP:coordinates = "TIME LATITUDE LONGITUDE DEPTH" ;
            TEMP:valid_max = 40.f ;
            TEMP:long_name = "sea_water_temperature" ;
            TEMP:ancillary_variables = "TEMP_quality_control" ;
            TEMP:units = "Celsius" ;
            TEMP:positive = "down" ;
            TEMP:axis = "Z" ;
      byte TEMP_quality_control(DEPTH) ;
            TEMP_quality_control:_FillValue = 99b ;
            TEMP_quality_control:standard_name = "sea_water_temperature status_flag" ;
            TEMP_quality_control:quality_control_conventions = "IMOS standard flags" ;
            TEMP_quality_control:long_name = "quality flag for sea_water_temperature" ;
            TEMP_quality_control:valid_min = 0b ;
            TEMP_quality_control:valid_max = 9b ;
            TEMP_quality_control:flag_values = 0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b ;
            TEMP_quality_control:flag_meanings = "No_QC_performed Good_data Probably_good_data
Bad_data_that_are_potentially_correctable Bad_data Value_changed Not_used Not_used Not_used Missing_value" ;

TEMP = 28.623, 28.628, 28.629, 28.63, 28.629, 28.63, 28.628, 28.627, 28.629,
   28.629, 28.618, 28.616, 28.618, 28.614, 28.615, 28.609, 28.611, 28.608,

TEMP_quality_control = 3, 3, 3, 3, 3, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
   1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
```

QC codes shown in HISTORY records:

```
    string HISTORY_INSTITUTION(N_HISTORY) ;
        HISTORY_INSTITUTION:long_name = "Institution which performed action" ;
        HISTORY_INSTITUTION:Conventions = "GTSPP IDENT_CODE table" ;
    string HISTORY_STEP(N_HISTORY) ;
        HISTORY_STEP:long_name = "Step in data processing" ;
        HISTORY_STEP:Conventions = "GTSPP PRC_CODE table" ;
    string HISTORY_SOFTWARE(N_HISTORY) ;
        HISTORY_SOFTWARE:long_name = "Name of software which performed action" ;
        HISTORY_SOFTWARE:Conventions = "Institution dependent" ;
    string HISTORY_SOFTWARE_RELEASE(N_HISTORY) ;
        HISTORY_SOFTWARE_RELEASE:long_name = "Version/Release of software which performed action" ;
        HISTORY_SOFTWARE_RELEASE:Conventions = "Institution dependent" ;
    float HISTORY_DATE(N_HISTORY) ;
        HISTORY_DATE:calendar = "gregorian" ;
        HISTORY_DATE:long_name = "Date the history record was created" ;
        HISTORY_DATE:units = "days since 1950-01-01 00:00:00 UTC" ;
        HISTORY_DATE:axis = "T" ;
    string HISTORY_PARAMETER(N_HISTORY) ;
        HISTORY_PARAMETER:long_name = "Parameter that action is performed on" ;
        HISTORY_PARAMETER:Conventions = "GTSPP PC_PROF table" ;
    float HISTORY_START_DEPTH(N_HISTORY) ;
        HISTORY_START_DEPTH:long_name = "Start depth action applied to" ;
        HISTORY_START_DEPTH:units = "m" ;
        HISTORY_START_DEPTH:positive = "down" ;
        HISTORY_START_DEPTH:axis = "Z" ;
    float HISTORY_STOP_DEPTH(N_HISTORY) ;
        HISTORY_STOP_DEPTH:long_name = "End depth action applied to" ;
        HISTORY_STOP_DEPTH:units = "m" ;
        HISTORY_STOP_DEPTH:positive = "down" ;
        HISTORY_STOP_DEPTH:axis = "Z" ;
    float HISTORY_PREVIOUS_VALUE(N_HISTORY) ;
        HISTORY_PREVIOUS_VALUE:long_name = "Parameter previous value before action" ;
        HISTORY_PREVIOUS_VALUE:units = "1" ;
        HISTORY_PREVIOUS_VALUE:positive = "down" ;
        HISTORY_PREVIOUS_VALUE:axis = "Z" ;
    string HISTORY_QC_FLAG(N_HISTORY) ;
        HISTORY_QC_FLAG:long_name = "QC flag applied" ;
        HISTORY_QC_FLAG:Conventions = "GTSPP ACT_CODE table and CSIRO XBT Cookbook" ;
    string HISTORY_QC_FLAG_DESCRIPTION(N_HISTORY) ;
        HISTORY_QC_FLAG_DESCRIPTION:long_name = "Description of HISTORY_QC_FLAG" ;
        HISTORY_QC_FLAG_DESCRIPTION:Conventions = "GTSPP ACT_CODE table and CSIRO XBT Cookbook" ;

HISTORY_INSTITUTION = "Australian Bureau of Meteorology",
  "Australian Bureau of Meteorology", "Australian Bureau of Meteorology",
  "Australian Bureau of Meteorology", "Australian Bureau of Meteorology",
  "Australian Bureau of Meteorology", "Australian Bureau of Meteorology",
  "Australian Bureau of Meteorology", "Australian Bureau of Meteorology" ;

 HISTORY_STEP = "CSCB", "CSCB", "CSCB", "CSCB", "CSCB", "CSCB", "CSCB",
  "CSCB", "CSCB" ;

 HISTORY_SOFTWARE = "MQUEST", "MQUEST", "MQUEST", "MQUEST", "MQUEST",
  "MQUEST", "MQUEST", "MQUEST", "MQUEST" ;

 HISTORY_SOFTWARE_RELEASE = "2.0", "2.0", "2.0", "2.0", "2.0", "2.0", "2.0",
  "2.0", "2.0" ;
```

HISTORY_DATE = 26224, 26224, 26224, 26224, 26224, 26224, 26224, 26224, 26224 ;

HISTORY_PARAMETER = "TEMP", "TEMP", "TEMP", "TEMP", "TEMP", "TEMP", "TEMP",
"TEMP", "TEMP" ;

HISTORY_START_DEPTH = 0.67, 0.67, 1.34, 2.01, 2.68, 3.34, 102.51, 790.18,
899.3 ;

HISTORY_STOP_DEPTH = 1100.25, 0.67, 1.34, 2.01, 2.68, 3.34, 789.57, 898.7,
1100.25 ;

HISTORY_PREVIOUS_VALUE = 28.623, 28.623, 28.628, 28.629, 28.63, 28.629,
28.707, 13.768, 19.58 ;

HISTORY_QC_FLAG = "QC", "CS", "CS", "CS", "CS", "CS", "PI", "LE", "WB" ;

HISTORY_QC_FLAG_DESCRIPTION = "Scientific Quality Control applied",
"Surface Spike", "Surface Spike", "Surface Spike", "Surface Spike",
"Surface Spike", "Inversion probable", "Leakage", "Wire Break" ;

QC codes shown in FAULT and FEATURE TYPE variable:

uint XBT_fault_and_feature_flag_type(DEPTH) ;

XBT_fault_type:_FillValue = 0 ;

XBT_fault_type:long_name = "XBT_fault_and_feature_flag" ;

XBT_fault_type:valid_min = 0 ;

XBT_fault_type:valid_max = 65536 ;

XBT_fault_type:flag_values = 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768, 65536, 131072, 262144,524288,1048576,2097152 ;

XBT_fault_type:flag_meanings = "surface_transient wire_break wire_stretch hit_bottom electrical_leakage electrical_interference_interpolated electrical_interference_rejected high_frequency_noise_filtered high_frequency_noise_rejected no_good repeat_profile temperature_inversion temperature_offset temperature_eddy_or_front temperature_steps_or_structure depth_offset constant_temperature time_error position_error duplicate_profile test_probe probe_type_error" ;