XBT Operational Best Practices for Quality Assurance

Version 1.0

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1 Abstract

Since the 1970s, EXpendable BathyThermographs (XBTs) have provided the simplest and most cost-efficient solution for rapid sampling of temperature vs. depth profiles of the upper part of the ocean along ship transects. This manual, compiled by the Ship of Opportunity Program Implementation Panel (SOOPIP) a subgroup of the Global Ocean Observing System (GOOS) Observations Coordination Group (OCG) Ship Observations Team (SOT) together with members of the XBT Science Team, aims to improve the quality assurance of XBT data by establishing best practices for field measurements and promoting their adoption by the global operational and scientific community. The measurement system components include commercially available expendable temperature probes, the launcher, the data acquisition (DAQ) hardware, a Global Navigation Satellite System (GNSS) receiver, an optional satellite transmitter, and a computer with software controls. The measurement platform can be any sea-going vessel with available space for the equipment and operator, and capable of oceanic voyages across the regions of interest. Adoption of a standard methodology in the installation and deployment of the measurement system will lead to data quality improvements with subsequent impact on the computation and understanding of changes in the near surface ocean properties (e.g., heat content), ocean circulation dynamics, and their relationship to climate variability.

2 Introduction

XBT temperature measurements monitor changes of ocean temperature from sub-mesoscale to global scales, deriving key surface and subsurface currents to study meridional heat transport in all ocean basins and also supplement other observational platforms to assess the variability of the upper ocean heat content. Fixed XBT transects are established along regular shipping routes targeted for sampling based on our understanding of how the regional upper ocean dynamics and thermal structure may be linked to long-term climate signals, extreme weather events, ecosystem assessments, etc. XBT data are archived and distributed by a variety of international data centers and most of the data are made available on the Global Telecommunication System (GTS) within 24 hours of acquisition providing critical input for weather, climate forecast models and other scientific applications.

Since 1980, the Ship of Opportunity Program Implementation Panel's (SOOPIP) primary objective is to fulfill the global XBT upper ocean data requirements established by the international scientific and operational communities. Additionally, SOOPIP is specifically tasked with coordinating the exchange of recommended practices for the XBT network. Now involving 20 agencies from different countries distributing most of the XBT data in near real-time on the GTS, the importance of SOOPIP developing a coherent methodology for XBT data collection is clear. During the 6th International XBT Science meeting in 2018, the participants acknowledged the fundamental need for a set of best practices through an action item with this specific goal (IOC, 2018).

This paper represents SOOPIP recommended XBT operational best practices for quality assurance and is part of a suite of separate companion best practices documents to include:

- "SOT Vessel Recruitment and On-board Conduct"
- "Delayed Mode XBT Quality Control"
- "XBT Metadata Content and Format"

The XBT measurement system outlined in this document has been adopted for its logistical and financial viability for studies requiring large scale, high density and frequently repeated measurements of upper ocean temperature profiles. Some oceanographic research objectives require highly accurate temperature profile measurements at well resolved depths that the XBT cannot fulfill with its manufacturer-specified accuracy of ±

0.2°C and depths estimated from a time calculation. Argo autonomous temperature and salinity profiling floats that reach 2,000 m deep provide a global network of more accurate (± 0.002°C), year-round temperature profiles. The core Argo float mission, begun in 2000, is to maintain a gridded global coverage of over 3,000 of these profiling floats. However, Argo floats are quickly swept out of boundary currents where large-scale mass and heat transport occur and there is less spatial resolution of sampling by Argo floats in dynamic regions. A synergistic approach for understanding circulation in boundary currents and other applications calls for a mix of platforms, including high-resolution XBT transects, as well as gliders, Argo profiles, moorings and remotely sensed measurements (Morris et. al., 2021).

3 Equipment

This section discusses types of equipment commonly in use for XBT deployments and provides aids to the best selections. Installation, testing and maintenance of the equipment are covered in later sections. All prices (in USD) for equipment given here are typical as of this publication date (2021).

3.1 XBTs

XBTs provide the simplest and most cost-efficient solution for frequently obtaining temperature profiles along fixed transects of the upper ocean. The XBT contains a precision thermistor located in the nose of the probe and the DAQ card measures the resistance of the thermistor and converts it to temperature. The depth is computed empirically as a function of the time-since-water-contact using a fall rate equation (FRE). There are currently only two major manufacturers of XBTs in the world, U.S.-based Lockheed Martin's Sippican and Japan-based Tsurumi-Seiki Company (TSK). The choice of the probe is primarily based on which company the funding institution can access for purchasing. Each manufacturer has a variety of XBT models; the SOOPIP recommends Sippican Deep Blues or TSK T-7s, rated to reach a depth of 760 m at a ship speed of 20 knots, one of the most cost-effective probes (<$100 USD each). Though the probe is only rated to 760 m maximum depth, it is common that they reach nearly 1000 m, depending on ship speed, with equivalent data quality. The deepest reaching XBT is the Sippican and TSK model T-5, which are capable of reaching a depth of 1830 m but must be launched at a ship speed of 6 knots.

3.2 Launcher

The basic hand-held, manually triggered launcher design for both Sippican and TSK XBTs is the same and commercially available from these XBT manufacturers (~$1500 USD). A lever compresses 3 sharp electrical contact pins onto the XBT canister with a cable connecting it to the DAQ system; the user holds the launcher over the ship side and pulls the pin that secures the XBT inside the canister, releasing the XBT probe to drop overboard.

Manufacturers and different institutions have developed their own launchers capable of holding multiple XBT probes and allowing remote, automated triggering of the XBT launch. Advantages of auto launchers include: a greater percentage of successful profiles, less frequent trips on deck in bad weather, more rest for the field technician when sampling is around the clock, and programmable drop intervals that help avoid missed stations. Disadvantages include: larger weight and volume of equipment for shipping and storage aboard, and more potential for equipment failures due to the increased complexity over hand launchers. The cost of developing an auto launcher has too many variables to estimate here but savings could be achieved by producing an auto launcher developed by another organization with their cooperation.

Ultimately, SOOPIP does not specifically recommend either automated or manual hand launchers; this decision should be based on meeting the needs and budget of the users. However, if an auto launcher is used, a hand launcher should also be available as a valuable troubleshooting tool and backup in case of auto launcher component failure.

3.3 Data Acquisition Hardware

Both Sippican and TSK offer DAQ hardware (proprietary electronic circuit cards with optional enclosures and cables) for processing the XBT signal, that provide results within the prescribed precision and accuracy parameters established for XBT technology (~$5000 USD for Sippican LMC-16 PCBA, circuit card only). Additionally, DAQ cards can be designed in-house, such as the Turo data recorder which was originally designed for use for the XBT program at the Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO). Whichever DAQ hardware is used, its performance in combination with the entire XBT system to achieve ± 0.2°C accuracy should be well validated before implementation.

3.4 Software and Computer

The computer can be quite basic, only needing the correct data cable connectors and system requirements for operating the equipment control software. A suitable laptop style ($500 USD) is recommended to reduce shipping and bench set-up space.

Equipment control software can be obtained from the DAQ hardware manufacturer or custom designed.

The foundation of the software design should be geared toward the users' needs but the following features are recommended to be included:

- Interface with the GNSS receiver – Continuously display the position and capture it for each profile eliminating manual data entry errors. Perform internal checks to alert the user of possible position data errors. An option to manually input positions is recommended in case of primary position source data failure to avoid missed stations.
- Automatically trigger an XBT release or alert the operator when a prescribed data collection point is reached. This can be based on time, distance or position.
- Capture Metadata – Metadata requirements as established by the SOT-10 Task Team on SOOP Metadata (WMO, 2019) and described in the companion document to this best practices suite "XBT Metadata Content and Format", should be captured and attached to each profile data set.
- For each temperature profile, preserve the raw signal data for the profile as well as calculated temperatures and depths.
- Transmit Data – The program should create a data file that is appropriate for transmitting in real time from the ship to the shore. Preferably, the software should be able to interface with the transmitter to automatically send profiles as they are bundled and alert the user of transmission failures.
- Translate and record the XBT signal to 3 decimal places - Although the accuracy of XBTs is significantly lower, noise signals of this magnitude are good indicators to alert the operator of data problems.
- Alert the operator of various system failures such as loss of GPS signal.
- Capture initial quality control (QC) flags either generated from user input or from an automated evaluation.

3.5 Global Navigation Satellite System (GNSS) Receiver

An accurate position (latitude and longitude) is required for each XBT profile collected. Global Positioning System (GPS) offers the most globally reliable coverage and accuracy of any single global navigation constellation, so it is best to select a receiver with access to GPS satellites to prevent loss of positioning signal. With many varieties of affordable and accurate GPS devices commercially available (~$100 USD), nearly any model which can be interfaced with the implemented computer controls is acceptable. The receiver's position data should be interfaceable with the computer to avoid user-input errors rather than relying on displays and manual input. Many models of transmitters also have integrated GPS, eliminating the need for a separate GPS unit. While a separate display is not required, it is an excellent verification tool to make sure that position data input to the program is correct. Additional features such as outputs for speed and heading may be required depending on the software controls used.

3.6 Transmitter

The value of XBT data for climatological applications is increased by making the data widely available to the community in as near real-time as possible. Where budgets and field conditions make it feasible, data transmissions from the ship to shore should be implemented. Near real-time transmission also allows for an additional quality check of the profiles during the cruise. Iridium transmitters are a good transmitter choice (~$1500 USD including antenna) because they have low data price rates (~$1 USD/profile depending on connection time) and can be used as a dial-up modem to establish a PPP connection to the Internet with data files transferred via FTP. The use of FTP instead of SMTP is recommended as a cost-saving option due to the ability of FTP connections to resume data upload in case of connection drops, which can be common in remote ocean locations. Because Iridium providers typically price transmissions based on connection time rather than file sizes, several profiles can be bundled together to reduce costs. Iridium Short Burst Data service is costlier and Inmarsat is even more expensive than the Iridium FTP transfer option.

3.7 Cabling

Cables, used on deck from the exterior XBT probe connection point to where it connects indoors to the data acquisition system, vary according to application. In any long-term installation, the cable should be durable against damage from wear, weather and ultraviolet radiation. The cable should include shielding from electromagnetic interference often present on ships. Connectors should be low resistance, exterior connectors must be waterproof and, if metal connectors are used, they should not come in contact with the ship's metal hull. A cost-efficient alternative to heavy duty, shielded cabling that does not need to withstand long-term deck installations is CAT6, which employs twisted pairs of wires and a differential amplifier so should not require shielding in most environments. Alternatively, implement a wireless solution.

3.8 Power Conditioner

A source of clean power is essential to avoid interference with the probe signal, so power protection devices are needed. Sippican recommends the use of an ultra-isolation transformer (~$800 USD) to isolate the system from the ship's ground. A marine-grade uninterruptible power supply (UPS) is another option for power conditioning (~$400 USD).

3.9 Test Probes

Test probes can be purchased commercially or custom built. Ideally, the test circuit will include all components of the XBT system, except for the XBT probe itself and provide a temperature simulation. Some test probes may only act to test the functioning of the system without providing a temperature profile simulation; while this is better than no test, it is highly recommended to use a temperature test probe. Other test probes may bypass the launcher, thereby testing the electronics only, but this will not reveal if there are any problems with the launcher cables or connectors. Important diagnostic information can be revealed using a mono-temperature simulating test. There is also value in having multiple reference temperature probes between 1-30 °C to cover the range of ocean temperatures by using good quality standard resistors to simulate the desired temperature. Verify that temperature test probes perform to an order of magnitude better than the XBT temperature sensor in precision and accuracy by repeatedly recording the simulated temperature reading for the duration of a normal XBT profile. See Section 4.1.2 for further discussion on testing the system.

3.10 Platform

With the permission and cooperation of ship owners and operators, the XBT platform can be any sea-worthy vessel with available space for the equipment and operator and capable of oceanic voyages across the regions of interest at the required frequency. Utilizing ships of opportunity, whether they be sporting, military, commercial, research, or fishing, allows for significant savings in data collection because these vessels are already employed on their usual business, eliminating chartering costs. Many ships will volunteer berthing space, while others charge a nominal fee for food and board ($10-$35 USD/day). The selection, recruitment, and interaction with suitable vessels are explained in great detail in the companion document to this suite of best practices “SOT Vessel Recruitment and On-board Conduct”; use that guide for logistics in preparing to meet the selected vessel. Anticipate what equipment, fittings, and tools specific to the vessel’s design might be needed in addition to materials specified in this document.

3.11 Distance Measuring Tool

The height of the launch location above the surface of the water should be measured to incorporate in the FRE for improving the profile depth calculation (Bringas and Goni 2015). A laser distance measuring tool ($50 USD) provides the most accurate actual height for a loaded vessel underway.

3.12 Spare Parts and supplies

If costs, convenience, and space were no barrier, the spares could comprise a complete backup system. In general, the minimum recommended spare parts are those most likely to fail and that cannot be done without, such as: hand launcher, cable connectors, DAQ hardware, computer, and GNSS. Complete the equipment list with additional supplies such as multimeter, flashlight, electrical kit, and toolkit to be prepared for all eventualities and to avoid borrowing ship’s tools and office supplies.

4 Deployment

As previously mentioned, the XBT measurement system is an easily deployed and economical method for obtaining ocean temperature profiles as deep as 2000 m where accuracy on the order of a tenth of a degree Celsius is acceptable. The simplest hand launcher system can be transported in a case the size of a large piece of airline passenger luggage. It can be operated by a single field technician without advanced technical knowledge, requiring about 5 minutes per collected profile. By taking advantage of ships of opportunity and the personnel who work aboard as operators, vessel chartering and field technician costs could be reduced to zero. Typically, for high density lines (i.e. where an XBT probe is deployed every 10-30 km), a field technician is supplied by the organization and paid at their contracted rate. Additional personnel resources (excluding travel and days spent at sea) are estimated in person-hours as follows: project management including recruiting and scheduling vessels, 8-40 hours per voyage; pre-deployment equipment preparations and packing, 8-40 hours; system installation or removal aboard, 8 hours; data post-processing and quality control 0.5-5 minutes per profile.

4.1 Pre-deployment Preparation

Careful preparation in advance of the mission is critical for data quality assurance and to avoid failures that result in reduced data collection.

4.1.1 Planning

The critical importance of travel, logistics and schedule planning cannot be overstated. While not included for an in-depth discussion in this document, some example pitfalls include:

- International transportation of equipment is fraught with complexities from the industry and authorities.
- SOOP vessels are often subject to the vagaries of weather, ports, and management that can delay or re-route ships without notice.
- Failure to anticipate or understand travel restrictions and requirements to foreign countries can easily derail all the other careful preparations.

See the companion document “SOT Vessel Recruitment and On-board Conduct” for more tips for creating successful data gathering opportunities.

4.1.2 Testing

Each component of the system including all cables *and* spare parts should be tested in the laboratory immediately prior to field deployment. Assemble a complete system in the lab and use a test probe to initiate a series of drops. Do not forget to include in the setup any cable extensions that may be needed on larger ships. Even in the laboratory, power conditions can fluctuate, so performing these drops over days or weeks may reveal otherwise hidden power susceptibilities. Exhaustive repeat testing is important when using new manufacturers or component models which have not been in the field before.

When using a temperature test probe, there should never be any drift in a test profile, even drift and noise an order of magnitude smaller than XBT accuracy are indicative of systemic problems. Noise and drift may not be apparent graphed at full scale, such as 0-25°C, so expand the graph scale of the temperature recording to visually reveal noise signals as small as 0.001°C. Example profiles from a nominal 1.5 °C test probe illustrate normal test data (Figure 1a) and test data that indicates a problem with decaying drift (Figure 1b). If only viewed at a coarse temperature scale on a small laptop monitor, these indicators would be invisible due to their small magnitude.

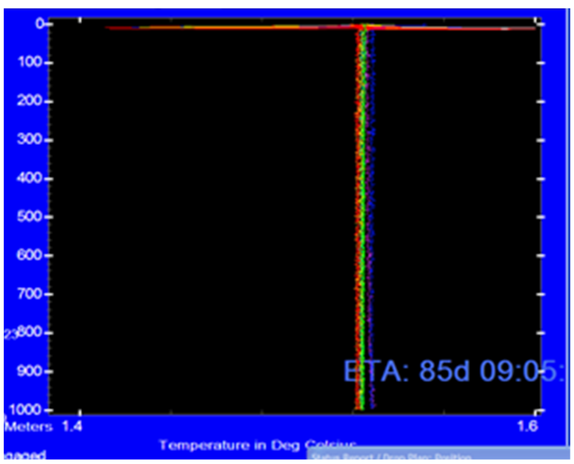

Figure 1a: Normal XBT Test Data

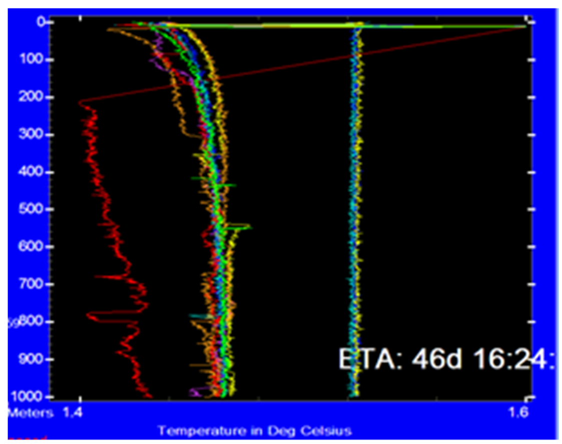

Figure 1b: Abnormal XBT Test Data

Learn to recognize the usual characteristics of the expanded scale, well performing test profiles. See section 6 “Accuracy and Precision” for further discussion.

The test probe can also help identify if there is a short in the system which causes data collection to begin before the XBT has entered the water. The test probe should only begin displaying data after it is connected to the ship’s ground, if data is displayed without a ground connection, a short is indicated that will cause erroneous data from XBTs known as “false splash”

Identify any components that are faulty or the source of noise or drift outside of accepted parameters and replace or repair them before field deployment. Common noise sources are grounding points, cable connections, power supplies, a failing DAQ card, faulty test probes, and heavy equipment being operated on the same electrical system.

Carefully inspect the integrity of all system components before deploying into the field. Create maintenance schedules that are integrated into checklists and/or cruise reports to include at least the following:

- Verify data quality performance using test probes.
- Verify that the system's mechanical and programmatic components operate without failure.
- Inspect the integrity of cable insulation, connection points and weather exposed seals.
- Operate and lubricate moving parts.
- Provide replacement batteries for computers and peripherals.
- Verify the function of spare components that will be sent into the field.
- Update computer security and create recovery media and disk storage space.
- Verify that the GNSS receiver updates with accurate position, date and time.
- Send test data via the transmitter ensuring the settings and subscription service are current.
- Double check software inputs including platform metadata.
- Verify that Personal Protective Equipment (PPE) is present and undamaged.

4.1.3 Prepare a Sampling Plan

The location and frequency of XBT deployments depend on the region under study, the purpose of the study and the budget. For example, boundary currents are important areas for studying heat transport so these regions would have a higher sampling frequency on a trajectory perpendicular to the current flow while sampling in an open ocean basin could be less frequent. In advance of the trip, develop a sampling plan with these factors in mind in conjunction with the anticipated ship track. Preset sampling locations of latitude *or* longitude (exact locations are impractical due to inevitable course changes) developed for the scientific objective are ideally programmed into the equipment control software to monitor the GPS position and automatically launch a probe or alert the operator to do so. If there are factors making a position sampling plan too complex, alternatively a time or distance plan can be implemented for designated intervals.

Within SOOP, XBT deployment transects are designated as low-density, frequently-repeated, and high-density or high-resolution. "Low-density transects typically target 12 realizations per year, with XBTs deployed at 150–225 km spacing, and are designed to detect the large-scale, low-frequency modes of ocean variability. Frequently repeated [FR] transects typically target 12–18 realizations per year, with XBTs deployed at 100–150 km spacing, and are designed to obtain high spatial resolution observations in consecutive realizations in regions where temporal variability is strong and resolvable with an order of 20-day sampling. High-density (HD) [or high-resolution (HR)] transects target four realizations per year, with XBTs deployed at ~10-25 km spacing, and are designed to obtain synoptic high spatial resolution resolving the spatial structure of mesoscale eddies, fronts, and boundary currents" (Abraham et al., 2013) (Goni et al., 2019).

Exclusive Economic Zones (EEZs) are where coastal nations have jurisdiction over ocean natural resources and so prior permission may be needed from the nation before sampling is permitted. Before commencing a sampling plan, know the boundaries and rules associated with any EEZs in the region under study. Failure to do so could subject the vessel and the program to serious fines and other consequences.

4.2 Field Installation

As discussed in greater detail in the companion document "SOT Vessel Recruitment and On-board Conduct", the three most important aspects of proper field installation for all SOOP operations consists of safety, performance, and aesthetics.

- **Safety:** Equipment must be secured in place in a manner appropriate to the extreme weather and rolling encountered at sea. It should not inhibit the operation of hatches, safety equipment, nor personnel movement. Proper PPE is essential for safety and compliance, including a minimum of a helmet, visibility vest, and safety shoes plus a life vest when at sea. Before working outboard on any deck, secure all tools and equipment with a lanyard so they cannot drop on personnel below or overboard.

- **Performance:** Selecting the most suitable location for equipment minimizes failures and ensures the best quality data.
- **Aesthetics:** It is important to project professionalism while working with program partners. Aesthetics matter to avoid a negative impact on the host vessel because not only is an untidy installation visually unappealing, it also looks unprofessional and can attract uncomfortable attention of inspectors who could raise questions for which the officers may be unprepared. Communicating and planning equipment locations with the ship's master and/or Chief Engineer can help avoid violations and inconvenience to the ship.

4.2.1 Equipment Placement

XBT Probes: Identify a storage location as close as practical to the launch location. Where possible, XBT storage should be climate controlled to prevent damage from excessive heat, freezing, or humidity. High temperatures can cause the wax, glue, and wire insulation to degrade. With those precautions in mind, XBTs ready for launch should be as close as practical to the sea surface temperature to minimize the time for thermal equilibrium of the temperature sensor upon water contact; don't store probes for arctic deployment in a heated space, nor those for tropical deployment in an air-conditioned space. (Cook and Sy, 2001). Store XBTs in their packing boxes; a common cause of XBT failures are wire snags which can happen when the wire slips on its spool from too much jostling, vibration or impact. Keep shipping to a minimum and transport on a pallet to reduce handling wherever practical. Proper handling and storage of XBTs ensures fewer failures due to probe quality and therefore, fewer missed data points.

Launcher: The most important aspect of selecting the launcher location is to minimize the possibility of contacting the XBT wire with any part of the ship. The launcher and operator should be out of reach of ocean swells. Position the launcher on what is expected to be the predominantly leeward side for the voyage, keeping in mind that it may need to be moved if unfavorable wind conditions persist. Avoid locations where deck structures could create air flow eddies that pull the light XBT wire on board. The launcher should be about 3-4 meters above the water line (Bringas and Goni, 2015). Avoid locations near where solids are discharged overboard, such as garbage chutes.

Auto launchers are typically mounted on the aft railing on the lower-most deck, as far port or starboard as possible to avoid propeller turbulence. Auto launchers are heavy, make sure that fasteners are secure and appropriately sized for the load; always secure them with a safety tether before mounting and dismounting.

Hand Launchers are also best located on the lowest deck away from turbulence but they do allow for more flexibility in their location. For example, a hand launcher on the bridge deck has the advantage of using the resource of bridge personnel for data gathering. Note that, where the bridge is high above the water line and forward of interfering ship structures, there will be more failures of XBTs launched from the bridge.

Cabling: Safety First! Cabling should be installed to avoid damage, avoid tripping hazards, should not prevent the latching of hatches and portholes, and should not block the overboard access of lifeboats/life rafts, nor personnel access to any lifesaving equipment. For example, do not attach a cable to the light beacon of a life ring, nor string the cable across a rarely used access to the lifeboat boarding area. Take care that cables are not damaged by hatches. Cables should be taut, with frequent attachment points to avoid getting snared by workers' limbs or tools such as lashing rods or fire hoses. Be aware that some spaces are forbidden for cable runs while other spaces require cable attachments to be metal so they do not melt in a fire. Where possible, cables crossing walkways should be routed overhead, otherwise, use a cable ramp. Reinforce chafe points with extra layers of insulation. For long cable runs, leave a service loop of cable at connection points to allow repairs without the need to remove the entire cable.

Control Equipment: The system's electronic controls (computer etc.) should be in a climate-controlled space that can be safely accessed in all conditions. Overheating is not only the enemy of computers but has also been shown to cause errors in the DAQ electronics. Secure all components to prevent slipping during rolling in heavy weather. If this is a shared workspace, decrease the bench footprint by securing components that do not need to be accessed on the floor or in a cabinet.

Transmitter and GPS: The antennae of these instruments depend on a clear view of the sky to the horizon to communicate with satellites. Sometimes, a GPS antenna can be set just inside a window and will receive an adequate signal but it is critical that the signal remains consistent because a data profile with a missing or inaccurate position is a useless data profile. Transmitters have fewer satellites available, which can be blocked by deck structures and so are best mounted atop the bridge.

4.2.2 Grounding

The launching system must be grounded to the ocean (referred to as the "seawater ground"), by connecting the system grounding point to the ship's metal hull with a minimum 3.3 mm^2 cross sectional wire. Depending on the system, the grounding point may be at the launcher or the DAQ system, but never both. For non-metal hulls, connect to the rudder shaft or ship's plumbing. Do not use the ship's electrical ground as the system grounding point. A poor ground will cause major flaws in the data and is arguably the most common installation failure. Test the quality of the ground using an ohmmeter with one lead on the system's ground and the other on exposed metal of the ship's hull *other* than the attachment point; the resistance should be less than 5 ohms. Jiggle the ground wire at both ends to make sure there is no major fluctuation in the resistance reading.

Multiple ground points in the system can create ground loops that cause temperature signal interference (Lockheed Martin, 2003). Avoid ground loops by eliminating connections to the ship's electrical ground at the DAQ hardware power supply. This can be accomplished by utilizing a power cable with no grounding pin at the receptacle end. The launcher ground point will function just the same as the DAQ hardware power cord ground pin so long as the launcher ground stays connected to the system. SAFETY NOTE: Establish the system ground first before connecting the system to the power receptacle and do not remove the system ground when the equipment is plugged in. Isolation transformers, surge suppressors and UPS should always be grounded normally with the third pin ground to the ship's electrical ground. Only the DAQ hardware that is connected to these power sources should have the power cord ground pin eliminated while maintaining ground through the system grounding point.

Ground the GNSS receiver to the ship's hull to protect against lightning strikes.

4.2.3 Power Considerations

Electrical interference caused by transient imbalances in the ship's active cathodic systems, electrical faults, electromagnetic transmitters, radio communication, and the use of heavy equipment on board can all interfere with the DAQ card, power supplies, or even the XBT probe wire acting as an antenna, sometimes at catastrophic levels (Cook and Sy, 2001). Viewing XBT test data at an expanded scale, as described in section 4.1.2 "Testing", is a good tool to reveal and diagnose electrical interference. The first line of defense is to use high quality power supplies in the system design. According to Sippican, some ship-induced problems can be remedied by use of an ultra-isolation transformer to isolate the system from the ship's ground. Other problems may benefit from a UPS, but it is essential to select a high quality, *marine-grade* unit. Surge suppressing power strips, if used, must be *marine-grade*. The electronics within UPS and surge suppressors designed for use on-shore are incompatible with ship power and not only can exacerbate the problem but also can be dangerous. Again, always make sure these units are connected to the ship's electrical ground via the manufacturer supplied grounded power cable. Sometimes a problem encountered with the power can be remedied by using a different circuit. Other times, the interference is transient and will go away on its own. For example, equipment on board such as cranes, welders, and grinders can cause electrical interference that will disappear when the equipment is not in use. Engaging the ship's electrician and engineers often helps to identify and eliminate ship sources of electrical interference.

4.2.4 Testing

Testing the system *in-situ* before beginning field measurements is just as important as the pre-deployment testing. Test to make sure installation is correct, to check for damage that may have occurred in transit, and also because power conditions on board are different than in the laboratory. Just as in the pre-deployment preparations, use a temperature test probe and expand the graph scale to reveal unusual trace patterns on the order of millidegrees and test for "false splash". Perform a test on each of the auto launcher positions (if used) and the hand launcher. Compare the results from each position to each other and to the results obtained from the pre-deployment tests. The appearance of the trace should be a straight line, no drift, with a maximum, minimum and nominal mean as expected. See section 4.1.2 "Testing", for the full discussion.

4.3 Field Techniques

4.3.1 Monitor the Sampling Plan

The sampling plan should have been established during the pre-deployment preparations but could require adjustment based on the actual ship's track or local conditions.

- **Avoid multiple drops in the same position** once a good profile has already been obtained for that position. For example, if the ship is drifting or on anchor, suspend a time-based or position-based plan.
- **Monitor course and speed alterations** to make sure the sampling plan objectives stay consistent with the new track or speed.
- **Monitor the data to change sampling as appropriate**. For example, the expected boundaries of an important current can change, so watch the data on the approach and increase sampling density as needed. Also, collect extra data profiles in a location where the data looked bad, questionable, or unusual.
- **Monitor EEZs.** Dropping XBTs is permitted in many EEZs but in the case where a known forbidden drop zone is on the route, or the ship diverts to such an area, alter the plan as needed.

4.3.2 Measuring the Launch Height

The launch height must be recorded and the XBT velocity factored into the FRE depth offset employed in data processing (Bringas and Goni, 2015), i.e. probes launched from the bridge 10 decks up will be moving faster than a probe deployed from the poop deck near the surface. This is most easily and accurately done using a laser distance measuring tool held at the same height and location as the launcher *while underway at the typical speed*. Some technique is required with this tool because if the water is too glassy and clear, the laser will not be reflected off of the surface of the water; in that case try and capture some white water directly below created by turbulence. Ship speed, position on the ship, and ship cargo lading all affect the height of any deck above the water. Therefore, the most accurate measurements of launcher height must be made under in-situ conditions. Alternatively, the height can be calculated so long as speed, draught, and squat tables (the ship's change in draught underway) from the vessel are incorporated in the calculation. Don't forget to enter the launch height in the metadata for each drop in case the launcher position is changed.

4.3.3 Launching XBTs

Once released, the XBT probe should enter the water as vertically as possible and its ship-mounted canister should be aligned as closely as possible with the angle of the wire's unspooled trajectory to minimize abrasion against the canister's opening. Fixed-mount launchers at the stern provide the most reliable vertical entry and should be set at a 10-30° angle downward from horizontal. Hand-held launching should release probes away from the ship's hull. While sometimes impossible, try to avoid probes tumbling or making water contact in a more horizontal position because that will reduce the fall rate. After the probe is released, the launcher can be held at the optimum angle for smooth wire unspooling.

4.3.4 Observing Data and Re-launching

Watch the progress of the data during the launch in real-time using either the commercially available system or a plotting interface capability developed by the user. Plotting the current temperature profile over the previous profile(s) can be an instant visual clue to alert of possible bad data. The profile should be fairly smooth and mostly similar to the previous profile collected nearby with no large temperature offsets, no high frequency noise, nor large, sharp spikes. See section 8 “Quality Assessment Methods” and CSIRO’s Quality Control Cookbook (Bailey et al., 1994) to identify profile characteristics and failure modes. If there is an unusual feature in the data profile, or when the data is obviously compromised, then another XBT should be launched as soon as possible. The subsequent temperature profile can confirm data features and ensure there is no data gap. If XBT probe costs are a concern, repeat drops can be limited to where suspect data is in the upper 200 m of the profile and/or where the observational area of the study is most critical.

If using an auto launcher, keep the hand launcher at-the-ready so it can be implemented without missing any station data. The more complex auto launcher can take a long time to troubleshoot and repair and might not be repairable in the field.

4.3.5 Weather Considerations

Weather conditions causing extreme ship motion, heavy rain, wind, or lightning can all negatively affect the data collection. Do not go on deck if conditions are too dangerous; check-in with the mate on watch and follow the master’s safety orders using extra precautions such as taking an escort and wearing a life preserver. Make efforts to ensure that the unspooling wire is not contacting the ship during the drop. At times, wind conditions can make this challenging, try changing the launch location to a lower deck or more protected area where deck structures are not creating eddies or obstacles. Lightning can cause severe spikes in the data profile for hours after it is no longer observable. Bad weather commonly results in wire stretching or breakage causing both obvious and subtle data errors (see section 8 “Quality Assessment Methods” for examples). When pre-loading the launcher, it is important to protect the loaded probes from rain. Wet probes may return data before entering the water, causing an observed early water contact or “false splash”. Observations and repeat launches should confirm if weather is the source of any bad data. If weather prevents successful launches, then resume launching as soon as possible after conditions improve.

4.3.6 Care and Maintenance

During the voyage, all equipment should receive regular maintenance to guard against damage from the harsh environment. Also, collect test data at the beginning and end of every cruise to verify system performance and stability.

Protect the launcher and any exterior equipment from salt and smokestack soot corrosion by rinsing with fresh water every day or two. When not in use, leave the empty probe canister locked in the launcher to protect the contact pins from corrosion. Cover the launcher as appropriate to protect it from severe weather such as ice. Lubricate moving parts with high quality lubricant appropriate to the materials. Lubricate rubber sealing components with a small amount of high-quality silicone lubricant without coating metal electrical contacts. Make sure electrical contacts remain free of salt, soot, dirt and oil; repair seals that are allowing intrusion of these contaminants. Inspect cabling for kinking, compromised connectors, and insulation damage; reinforce chafe points using additional insulation. Inspect attachment points for signs of loosening and material fatigue which are commonly caused by ship vibration, corrosion, and UV degradation. Protect corrodible parts with anti-corrosion coatings and canvas covers where appropriate. In between cruises, stow equipment off the deck in shipping boxes.

Indoor electronics should be regularly monitored for signs of overheating or moisture. Be aware that as the vessel changes course and position, a once cool location can become exposed to more sun or changes in the climate. Be careful not to dislodge cables and keep the area around the equipment free of dust. Electronics that are deployed for long periods can get clogged with dust inside their enclosures trapping heat, moisture, and corrosive salt from the air. If batteries are used, inspect for corrosion and leakage. Make an inspection schedule part of the cruise report and do not forget to include spare batteries and ancillary tools such as flashlights and multimeters.

5 Calibration

Individual XBT probes cannot be calibrated before use because any in-water test is destructive. In the past, changes in manufacturer methods or locations have caused changes in performance characteristics and reliability. While manufacturers do perform field and laboratory quality control exercises, it is recommended to do spot tests on a small batch of XBTs to ensure they perform to specifications as time and budgets allow. Refer to "XBT/XCTD Standard Test Procedures" developed for SOOPIP-III (Sy and Wright, 2000), for implementation of independent verification.

When a problematic batch of XBTs is discovered in the lab or in the field, track the probe serial numbers and date of manufacture (DoM) and cross reference against other probes from that time period to see how prevalent the problems are (this is why DoM should always be recorded in the profile metadata). The failure(s) should be documented and summarized for the manufacturer as that could lead to a discovery in factory problems which can be corrected in future batches. Good cooperation addressing quality problems and replacement probes have been obtained from both Sippican and TSK.

The proprietary electronics of Sippican and TSK DAQ cards also are not designed for calibration. An XBT temperature test probe with good quality standard resistors is the best method to ensure the entire system is performing according to specifications.

6 Accuracy and Precision

As stated by the manufacturers, the system accuracy of Sippican's Deep Blue XBT and TSK T-7s for temperature is ± 0.2 °C and for depth is 4.6 m or ± 2%, whichever is greater (Lockheed Martin, 2021). Note that under some conditions and with systems that are not well assessed, the accuracy could be worse. The startup transient is the depth at which the initial temperature signal has come to equilibrium with sea water temperature. At depths shallower than that, the temperature is outside of the XBT's stated accuracy and considered unreliable. Startup transient depth is commonly accepted to be <4 m, but has been shown to be DAQ card dependent and could be deeper, an important consideration to avoid systematic bias in sea-surface temperature (Kizu and Hanawa, 2002). The science community has determined that the nominal accuracy of XBT data is suitable for many scientific applications and bias-corrected historical data can be applied for climate research purposes (Cheng et al., 2016). Many studies involving XBT accuracy have been performed on volumes of historical data; for further consideration, a comprehensive list of XBT quality test references compiled by NOAA's National Centers for Environmental Information (NCEI) can be found on their XBT bibliography website (https://www.ncei.noaa.gov/access/world-ocean-database/xbt-bibliography.html). NCEI also offers a list of XBT corrections publications that discuss biases in the temperature data as well as fall rate errors (https://www.ncei.noaa.gov/expendable-bathythermograph-xbt-corrections). In addition, the International Quality Controlled Ocean Database (IQuOD) community (http://www.iquod.org) is actively working to construct a climate-quality temperature database from all collected temperature profile data by developing a consistent quality control standard (Cowley et al., 2021).

At the Scripps Institution of Oceanography SOOP XBT program, test measurements using the Sippican MK21 XBT system with nominal 1.5 °C XBT test probes are capable of producing results with noise ranges of ± 0.001 to ± 0.005 °C and with ± 0.005 °C repeatability. While the results are unpublished, it is a good estimate of observations on precision that span thousands of measurements on dozens of systems performed for over two decades. When DAQ cards that do not perform with this level of precision are identified, they are excluded from use in climate-grade measurements to reduce system bias as much as possible.

7 Standards

As described in section 3.8 “Test Probes”, XBT test probes provide the standard used for the XBT measurement system. The test canister coupled with the measurement system should perform at least an order of magnitude better than the stated accuracy of the XBT system of ± 0.2 °C in precision and accuracy.

8 Quality Assessment Methods

This section discusses real-time quality assessment observations and actions to be taken in the field. More rigorous evaluations and expanded QC flags can be applied in post-processing to produce delayed mode data, which is covered in the companion best practice article “Delayed Mode XBT Quality Control”.

The field technician is the first line of offense for great quality assurance, assessment and control. Upon identification of quality problems, the technician should notate data flags, immediately attempt to rectify the cause in order to avoid poor or missing data, and document the observations and steps taken in the cruise report.

Although it might be desirable, at present there is no single universally established QC flagging scheme and it is generally recognized that it is most realistic to accept diverse standards and translate between them (Bushnell et al., 2019). The Intergovernmental Ocean Commission (IOC) has proposed a two-level quality flag scheme for the exchange of oceanographic data. The primary level is defined by five flags and applied to any type of data that needs only basic flags. The primary level flags are complemented by the secondary level flags which are created by the group using the flags based on their specific needs and history (Intergovernmental Oceanographic Commission of UNESCO, 2013). The IOC proposal includes cross-references to some data flag schemes for different programs with a plan to keep the references current on the Ocean Data Standards website (https://www.oceandatastandards.org). SOOPIP recommends the use of the Global Temperature and Salinity Profile Programme (GTSPP) flagging scheme. Note the critical difference between IOC primary flags and GTSPP for the description of code 2.

Table 1: Flagging Scheme Comparison

Code	GTSPP Quality Flags (Used by SOOP)	IOC 54:V3 Quality Flags
0	No quality control has been assigned	
1	QC was performed; appears to be correct	Good
2	QC was performed; probably good	Not evaluated, not available or unknown
3	QC was performed; appears doubtful	Questionable/suspect
4	QC was performed; appears erroneous	Bad
5	The value was changed as a result of QC	

9	The value is missing	Missing data

XBT data and metadata to be flagged are date/time, position, temperature and depth. Note that the temperature profile could contain multiple flags, e.g., points from 0-250 m flagged as correct data, 251-350 m probably good, and 351-900 m erroneous. Ideally, the XBT software can do an automated data evaluation and QC flagging, or allow the user to input QC flags before any data distribution.

8.1 Evaluating XBT Profiles for Basic Failures

The operator is the only observer directly aware of existing field conditions that could be affecting data quality. Experience with temperature conditions in the region and additional data comparisons are excellent tools to help identify erroneous versus real temperature anomalies. In real-time, the operator should examine the temperature plotted against depth for high frequency noise, missing data, large temperature offsets, and sharp spikes. While apparent temperature inversions and constant temperature segments are often real-world conditions, they may also indicate errors caused by wire stretch, wire break or sea floor contact. Compare the current temperature-depth plot to that of the previous profile and if bad data or questionable data is observed, a repeat drop should be made as soon as possible, triggered either by the operator or by the software from its automated QC evaluation. The subsequent repeat temperature profile can confirm data features and ensure there is no data gap. Anomalous features that are present or hinted at in the previous profile and present in the repeat drop or the next profile, lend confidence to the data. In the absence of a repeat drop, neighboring profiles and archived historical data from the same geographical region are invaluable and should be graphed overlapping. Archived data sets can show if features such as large inversions, eddies, or multiple mixed layers are to be expected for the study area.

Examples depicting normal data as well as common failure modes and the descriptive QC flags for labeling them based on CSIRO’s Quality Control Cookbook (Bailey et al., 1994) can be found in the Appendix: Examples of XBT Data Profile Features. Although all of the QC flags might not be applied to the data profile in real-time, the examples are a helpful reference to understand XBT temperature profile data.

8.2 Metadata Verification

It is critical that the field technician takes care that all platform and measurement metadata are accurately recorded and transmitted as outlined in the WIGOS Metadata Standard (WMO, 2019). Ship-ID, DAQ card manufacturer and model, software and version, XBT probe information, drop position, date and time of deployment, launcher height, FRE coefficients, and QC flags are all examples of crucial metadata. Because different models of XBTs have different characteristics affecting their fall rate, it is important to not only use the appropriate FRE but also to include the manufacturer name, model, serial number, and date of manufacture in the metadata reported with each drop (WMO/IOC, 2019). SOOPIP upholds that “no correction scheme is applied to raw XBT data. All archived data should only contain depths calculated from either the manufacturers or the Hanawa et al. (1995) coefficients, and temperatures obtained from the collection system” (Cheng et al., 2016). Additionally, because the profile depth is calculated as a function of time, therefore, time since deployment should be also recorded explicitly or implicitly by knowing the sampling rate of the DAQ card.

When excellent metadata exists, researchers can revisit historical data sets and make improvements using corrections or adjustments based on knowledge enhancements that inevitably come with time, such as done by IQuOD. These adjusted data sets from disparate institutions using different equipment and techniques could be merged effectively creating a comprehensive, coherent, historical record. Indeed, during their Fourth XBT Workshop, the XBT Science Team made the recommendation of the work of Cheng et al. (2014) for historical data corrections and a comprehensive evaluation of errors past and present (Cheng et al., 2016).

8.3 Test Data Comparisons

In addition to testing the operation of the equipment after installation, test data should be collected at the start and the conclusion of every cruise. Re-testing should also be performed each time the DAQ card, launcher, cabling, or power supply is exchanged or repaired. Ensure that the system has remained stable by comparing lab test data to all field test data collected during the cruise. Verify that there are no deviations outside of expected results.

8.4 Cruise Report

A detailed report for each XBT cruise should be written and at least preserved with the original internal data archive. It should include all the metadata outlined in section 8.2 "Metadata Verification" as well as notations about equipment problems, their causes, equipment changes and repairs. Keep a daily log that includes regular observations of weather that could affect measurements, such as wind speed and direction, lightning, heavy rain, ice, etc. For each launch, note any unusual observations and the reason for profile flags numbered >1 (Table 1). Include statistics for number of drops, probes used, and probe failure rates. List supplies needed for the next voyage and summarize advice for the next technician. Tabulate and summarize the results of all test data. Document what procedural manual and best practices were used. Do not forget to specify the name and identifiers of the scientific project as well as any ancillary project operating at the same time on board, such as Argo or drifter deployments.

9 Data Management

All XBT data collected including paper copies of logs, cruise reports, and test data should be retained and archived by the group collecting it. It is a good practice to keep the data using multiple different storage methods such as: solid state archive, cloud archive and an accessible disk.

SOOP XBT data are additionally archived and distributed through NOAA/NCEI, the Australian Ocean Data Network (AODN) Portal, the institutions conducting the operations, and other regional data distribution centers.

Currently, SOT is working with other organizational task teams establishing the standards and procedures for platform and measurement metadata and also templates for Binary Universal Form for the Representation of meteorological data (BUFR format) for sending data to the GTS. Once this is formalized, there are plans to create the best practices companion document "XBT Metadata Content and Format".

10 Summary

The measurement of ocean temperature profiles of the upper ocean using XBT probes deployed in a global network of established transects continues to provide important data applicable to climate studies such as changing upper-ocean currents, meridional heat transport and thermosteric sea level rise.

The XBT measurement system in its simplest form is compact, inexpensive, robust, reliable, and easy to operate. The ubiquitous application of XBT probes, first deployed in about 1967, has led to long-term technological support of the product. Permanent components of the system, consisting of the launcher, DAQ hardware, GNSS receiver, computer controls and power, can last in excess of 10 years with careful maintenance and monitoring for stability (e.g. the launchers and DAQ card used by SIO's XBT program have been in service for over 20 years). The low cost of making a large number of closely spaced temperature measurements is the key reason for implementing this surveying technique. Costs can be further minimized by recruiting volunteer ship platforms and employing personnel already working aboard as operators.

The longevity of XBT measurement programs increases their relevance to global ocean circulation studies. While other temperature profiling platforms, such as the Argo core program, now contribute much high-quality data, “they cannot occupy repeated, mesoscale-resolving, trans-ocean basin transects across major currents on the time scales that are regularly sampled using XBTs from fast-moving ships” (Goni et al., 2019). On the other hand, the accuracy limitations and spatio-temporal specialization of XBTs require other techniques to offset the program data’s regional biases. Therefore, XBTs and other profiling platforms are complementary and also serve as cross references to identify biases in the Global Ocean Observing System. Because the XBT measurement system will continue to fulfill an important niche, the SOOP community remains active in promoting best practices, advances in the design of XBT probes, and a better understanding of their characteristics that will improve temperature measurement accuracy (Abraham et al., 2013).

11 Organizations/Acknowledgments

These best practices for XBT quality assurance rely heavily on the experience and unpublished operational manuals of SOOP’s most prolific XBT data contributors: Atlantic Oceanographic and Meteorological Laboratory, the Australian Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation, and Scripps Institution of Oceanography. The Ship of Opportunity Program operates under the Ship Observations Team (SOT), a network of the Global Ocean Observing System, Observations Coordination Group (GOOS, OCG).

The Global Temperature and Salinity Profile Programme (GTSPP) is an international cooperative developed by a group of marine science organizations to provide researchers and marine operations managers with accurate, real-time and best-copy temperature and salinity data. The World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) jointly manage the program’s network of capture, archive, and dissemination systems to ensure sustained quality control, storage, and access.

NOAA's National Centers for Environmental Information (NCEI) host and provide public access to one of the most significant archives for environmental data on Earth, providing comprehensive atmospheric, coastal, oceanic, and geophysical data. This includes maintaining GTSPP’s long-term archive by providing storage and quality control services to ensure that best-copy versions of GTSPP data are properly preserved and available to the public (https://www.ncei.noaa.gov).

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Mauro Cirano coordinates the NOAA AX97 High Density XBT transect, which is a multi-institutional effort that receives Brazilian funds from the Ministry of Science, Technology and Innovation and from CNPq research projects grants 405908/2016-4 and 443262/2019-5.

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12 Glossary of Terms

AODN Australian Ocean Data Network
AOML Atlantic Oceanographic and Meteorological Laboratory
BUFR Binary Universal Form for the Representation of meteorological data
CSIRO Commonwealth Scientific and Industrial Research Organisation of Australia
DAQ Data acquisition
FRE Fall Rate Equation is a function for determining probe depth based on time since water contact.
FTP File Transfer Protocol is a simple protocol for transferring files on the internet.

GNSS Global Navigation Satellite System
GOOS Global Ocean Observing System
GPS Global Positioning System, a GNSS constellation.
GTS Global Telecommunication System
GTSPP Global Temperature and Salinity Profile Programme
IMOS Australia's Integrated Marine Observing System
IOC International Oceanographic Commission
IQuOD International Quality Controlled Ocean Database
NCEI NOAA's National Centers for Environmental Information
NOAA National Oceanic and Atmospheric Administration, United States Department of Commerce
OCG Observations Coordination Group
PPE Personal Protective Equipment
PPP Point-to-Point Protocol is a protocol for communication between two nodes.
QC Quality Control
SIO Scripps Institution of Oceanography at University of California, San Diego
SMTP Simple Mail Transfer Protocol is a program used for sending emails using an email address.
SOOPIP Ship of Opportunity Program Implementation Panel
SOT Ship Observations Team
UNESCO United Nations Educational, Scientific and Cultural Organization
WMO World Meteorological Organization
XBT eXpendable BathyThermograph temperature profiling probes

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14 Appendix: Examples of XBT Data Profile Features

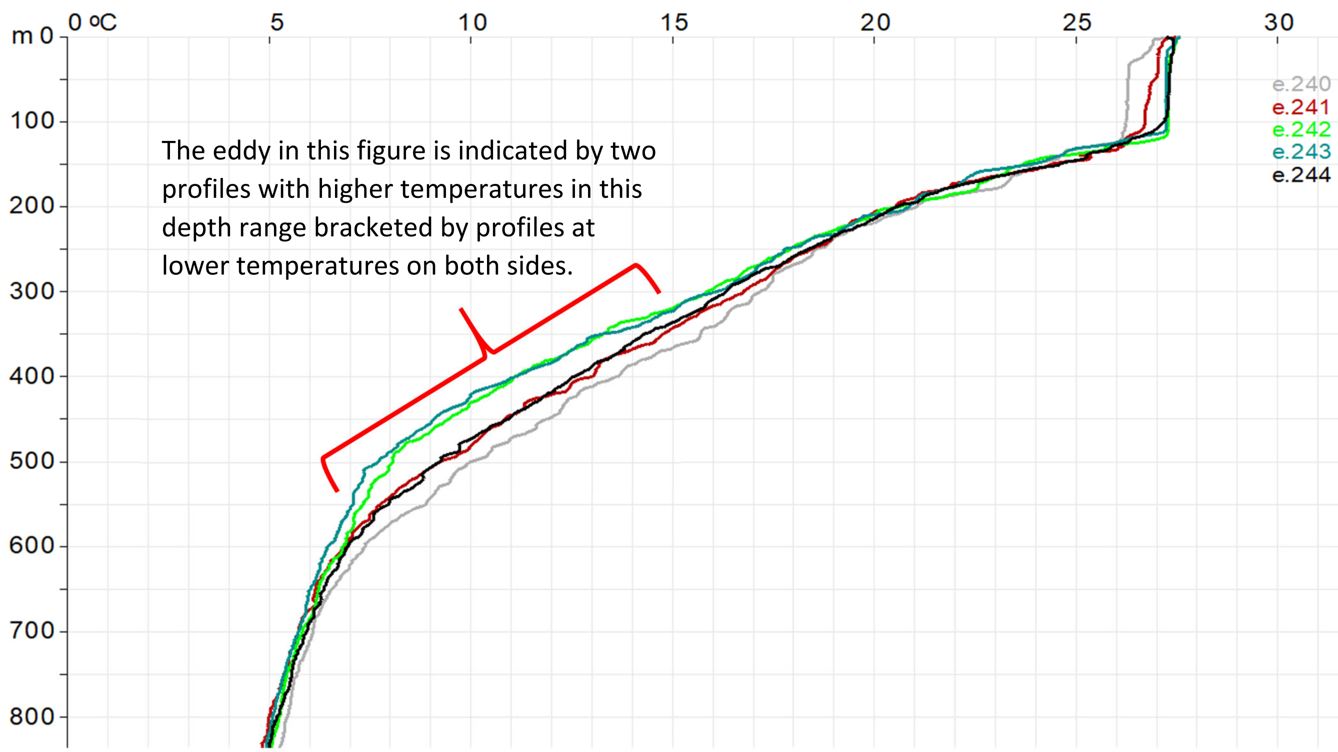
This section is organized by GTSPP QC flag codes (Table 1). Each code category includes a couple of profile examples with explanations from CSIRO's *Quality Control Cookbook for XBT Data* (Bailey, 1994).

14.1 Code 1 - QC was performed; appears to be correct

Eddy or Front Confirmed - Code 1

An eddy or front area is an increase or decrease in temperature over large depth ranges compared to neighboring profiles. A temperature displacement may appear in alternating or sequential drops as the ship track crosses a current, eddy system or frontal region. Repeat profiles showing similar temperatures at depth, or archive data can confirm the feature.

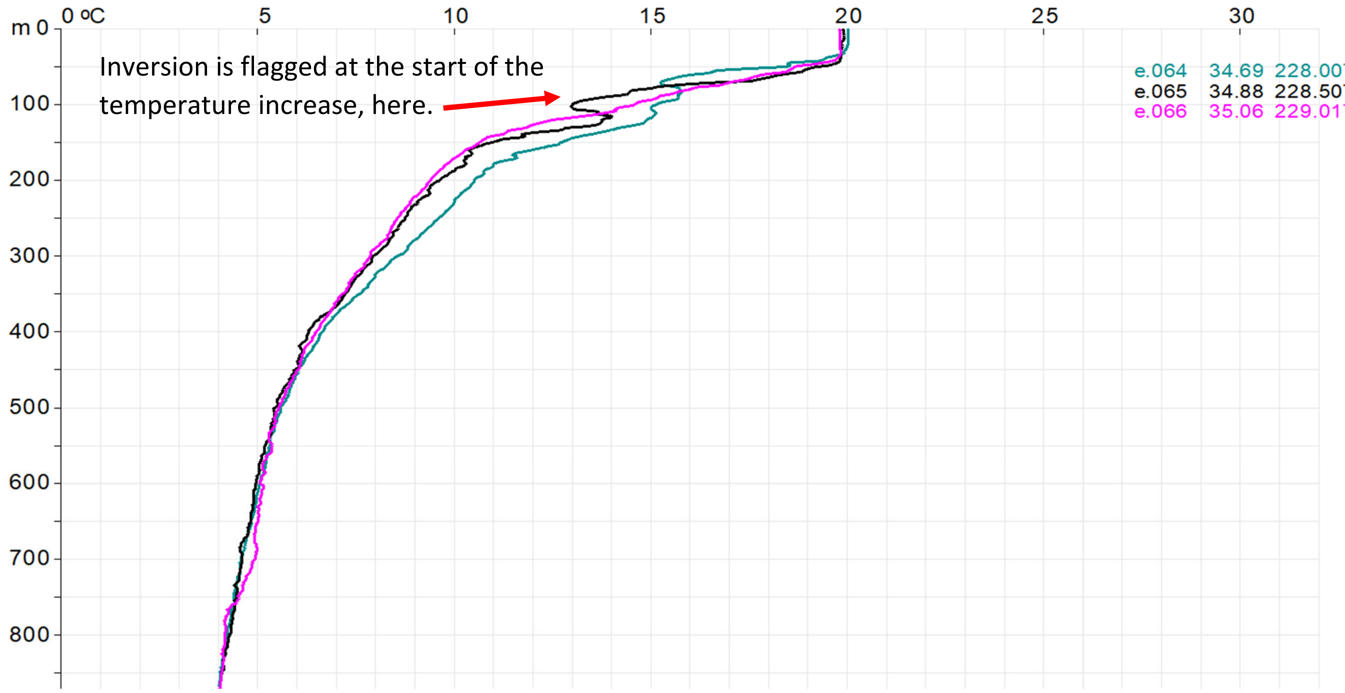
- ❖ The Eddy is flagged at the surface and the entire profile is code 1.



Inversion Confirmed - Code 1

An inversion is defined as a confirmed increase in temperature with depth observed at some point in the profile. Confirmation is established through the observation of the same feature in a neighboring or repeat drop. These features usually occur in specific regions.

❖ Inversion is flagged at the start of the temperature increase and the profile is code 1.

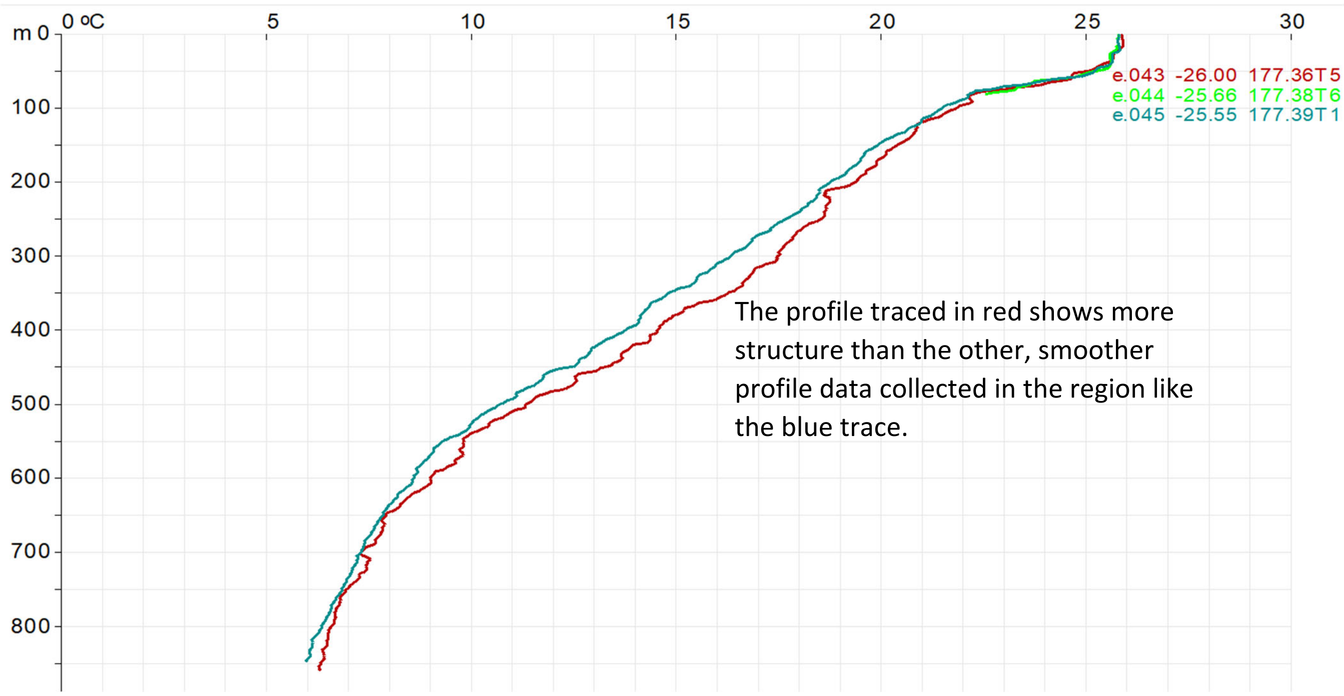


14.2 Code 2 - QC was performed; probably good

Fine Structure/Step Probable - Code 2

Fine structures or steps are flagged if structured step-like features are observed in a drop but cannot completely be confirmed by a neighboring profile. However, the feature is probably real because similar features have previously been observed in the region.

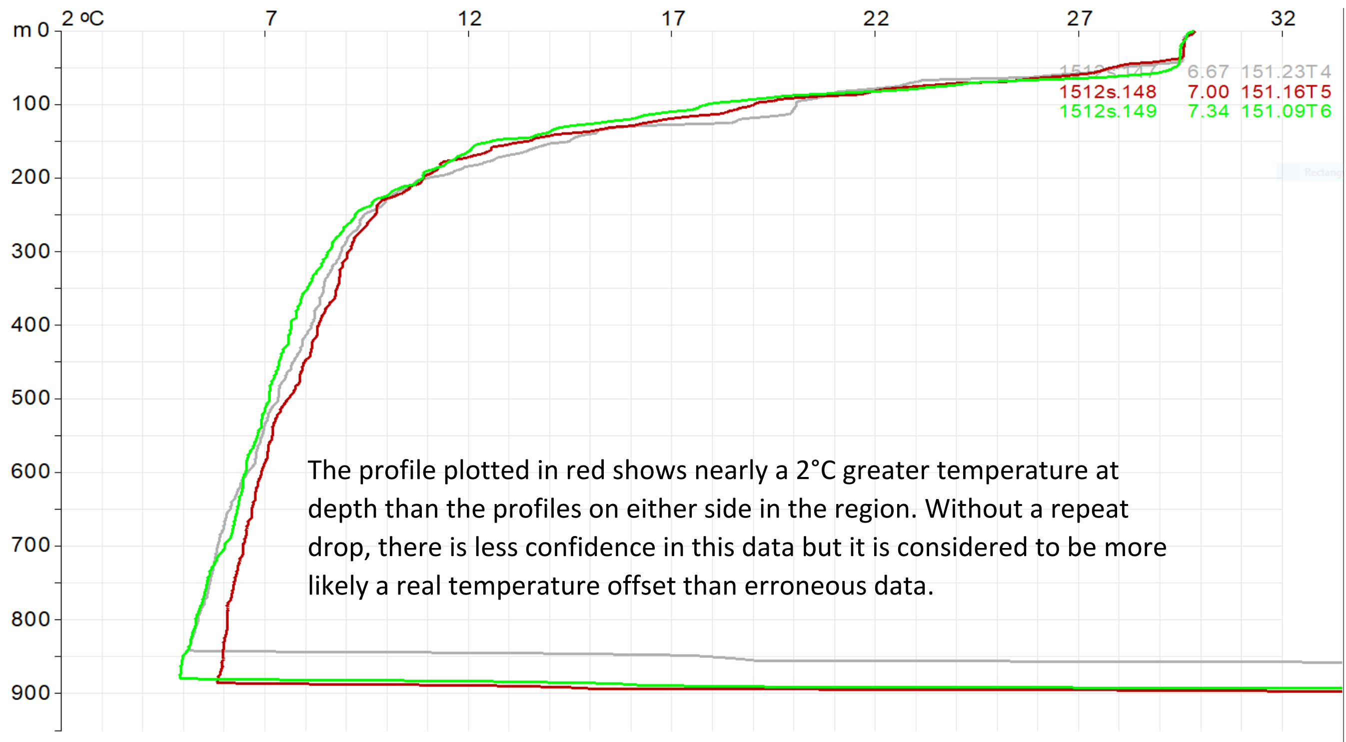
❖ Fine structure is marked at the surface and the entire profile is flagged as code 2, so don't use this flag if the profile is certainly good.



Temperature Difference at Depth – Code 2

This feature is flagged if a temperature difference (>0.2°C) at depth is observed when compared to neighboring profiles, though the difference can also occur over the entire profile. If this difference cannot be confirmed as real but eddies or fronts are known to occur in the region from archives, then the feature is considered to be probably real.

❖ Temperature is marked at the start of the temperature difference and all depths deeper are code 2.

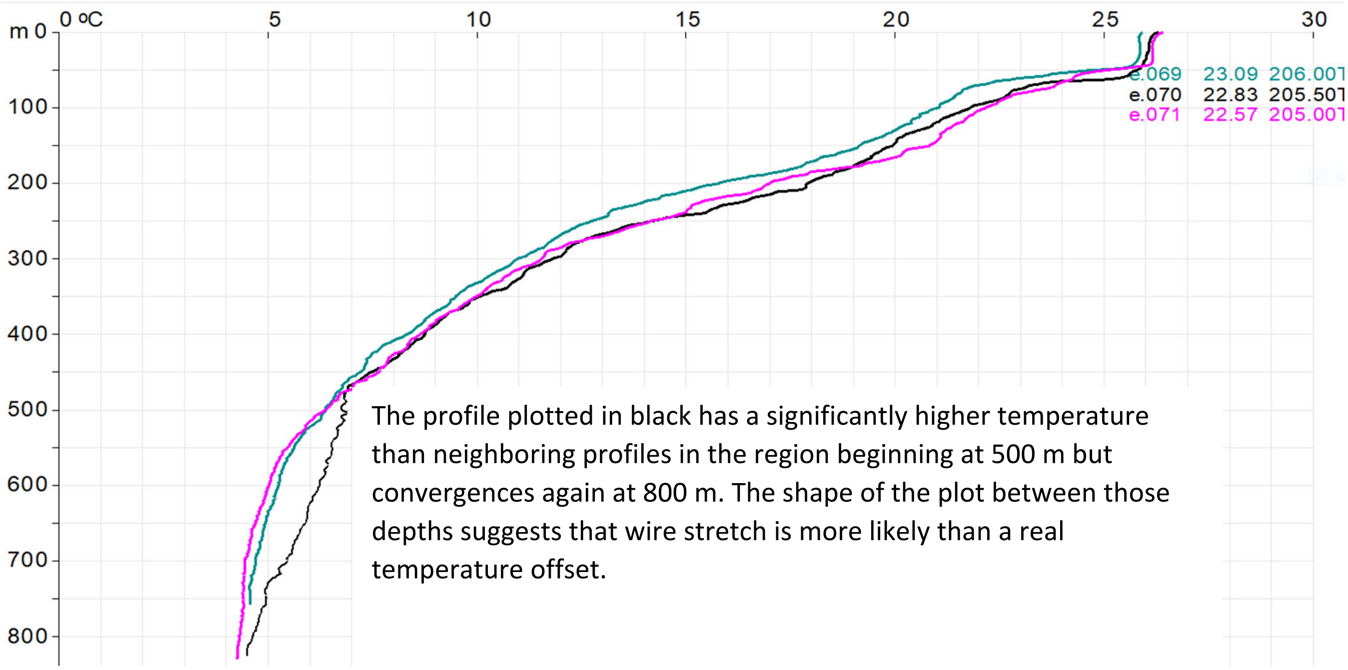


14.3 Code 3 - QC was performed; appears doubtful

Wire Stretch or Temperature Offset Possible - Code 3

A possible wire stretch is a small, apparent warming of temperature with depth at some point in the profile. Unrealistic temperature differences that cannot be confirmed by a neighboring drop and there is limited evidence that eddies or fronts occur in the region from archives are often caused by wire stretch.

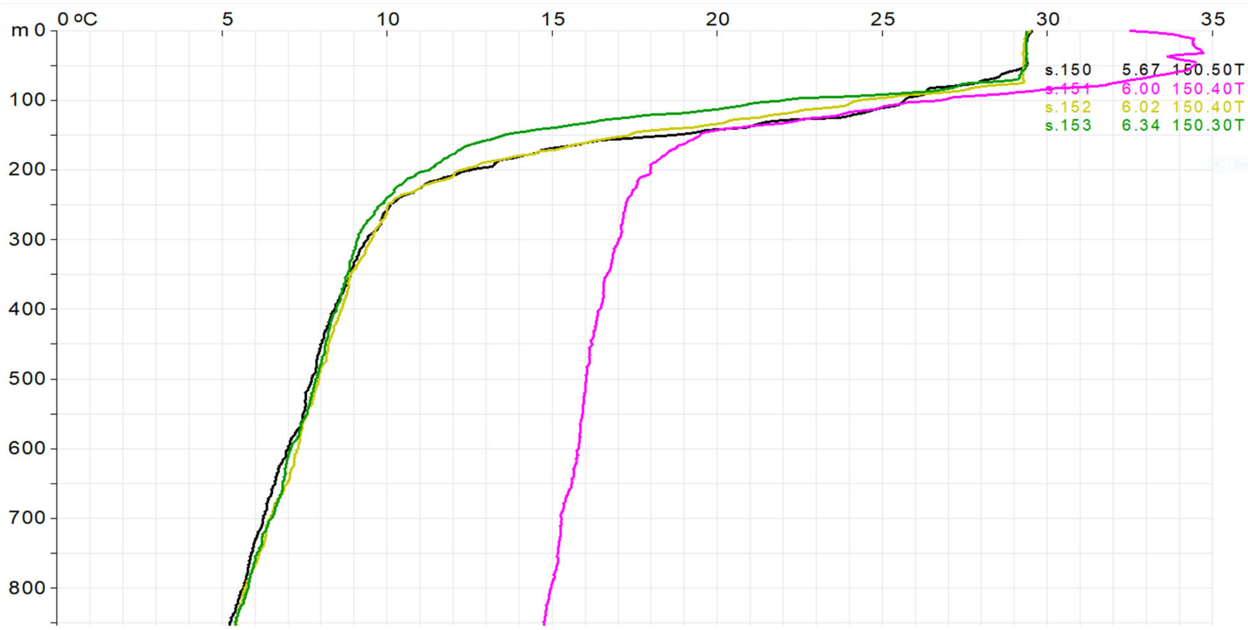
- ❖ Wire stretch is marked at the start of the suspected stretch and all depths below are code 3.



14.4 Code 4 - QC was performed; appears erroneous

Bad data throughout – Code 4

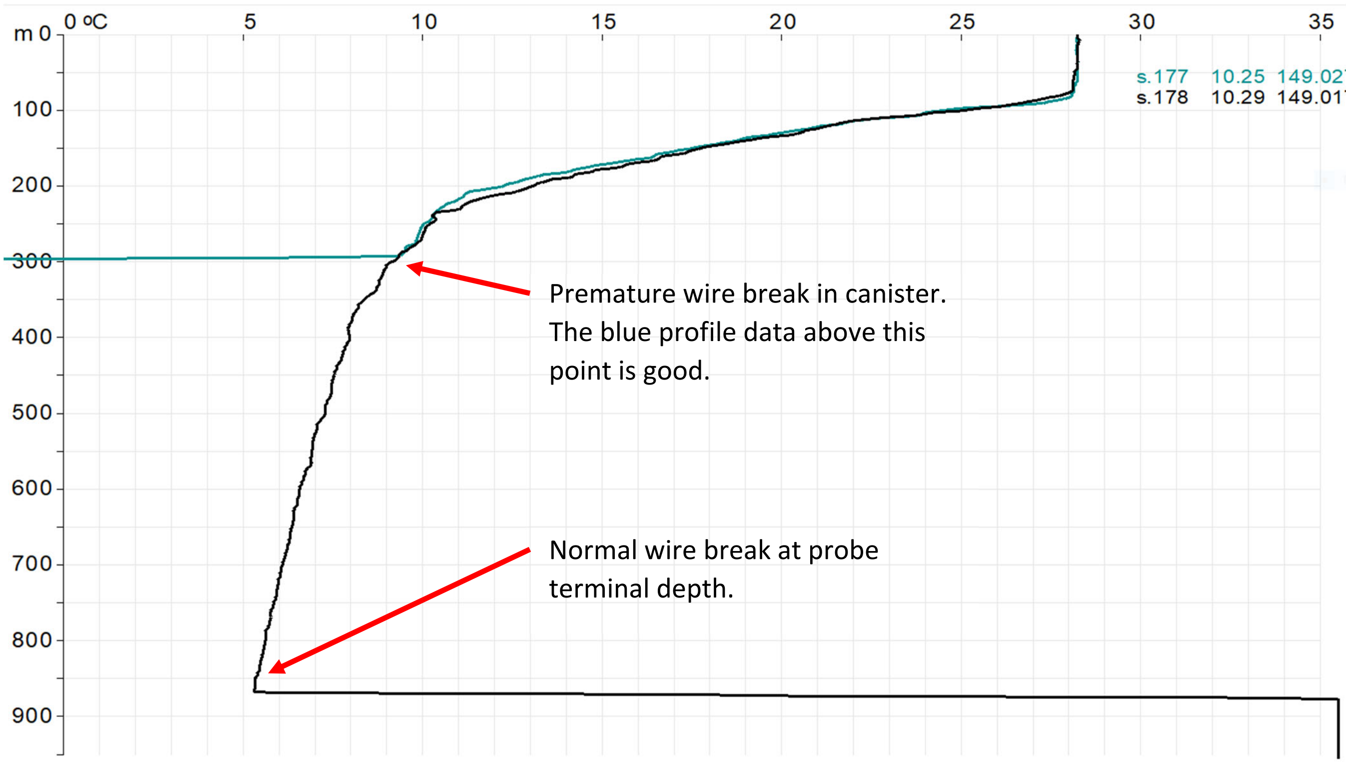
If the data is obviously erroneous throughout, as in the pink profile below, the entire profile is flagged as code 4.



Wire Break Reject – Code 4

When an XBT wire breaks, a short circuit causes the temperature readings to go off the scale either towards the low (when the wire breaks from the spool in the canister) or towards the high (when the wire breaks from the descending probe's spool) end of the temperature scale. The main causes of wire breaks are when the terminal depth of the probe is reached. A good XBT cast in deep waters ends in a wire break, but it can also happen shallower if the wire snags on something. Shallower wire breaks are often preceded by a wire stretch.

❖ Wire break is marked at the start of the deflection and the data below is flagged code 4.



Wire Stretch – Code 4

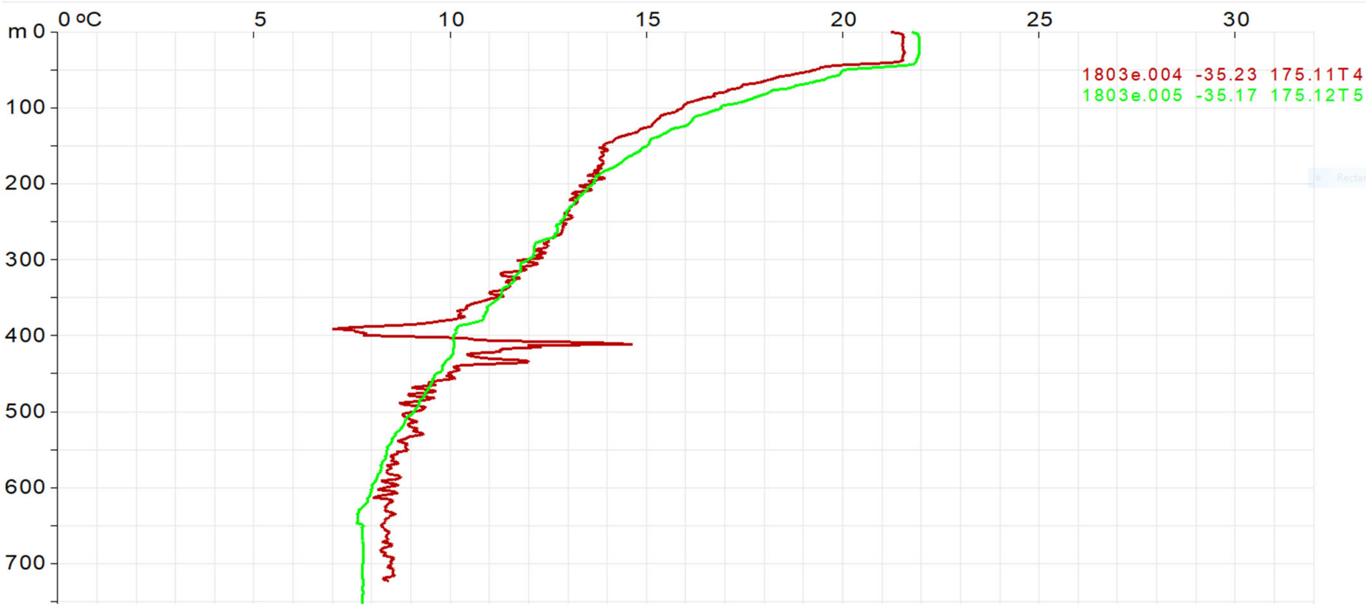
A true wire stretch causes an abnormal increase of temperature with depth (usually >0.2°C observed over a large range of depths). The feature is considered erroneous because temperatures at depth are inconsistent (warmer) when checked against neighboring profiles. A wire stretch is often observed at the base of a trace before a wire break, or if fouling or restricted unreeling occurs.

- Wire stretch is flagged at the start of the stretch and all depths below are code 4.

High Frequency Spiking – Code 4

Continual spiking over a wide range of depths that cannot be interpolated by filtering (it is not recommended to interpolate more than 10m), can be caused by leakage, insulation penetration or electrical interference.

❖ Spikes are marked at the start of spiking and all depths below are flagged as code 4.

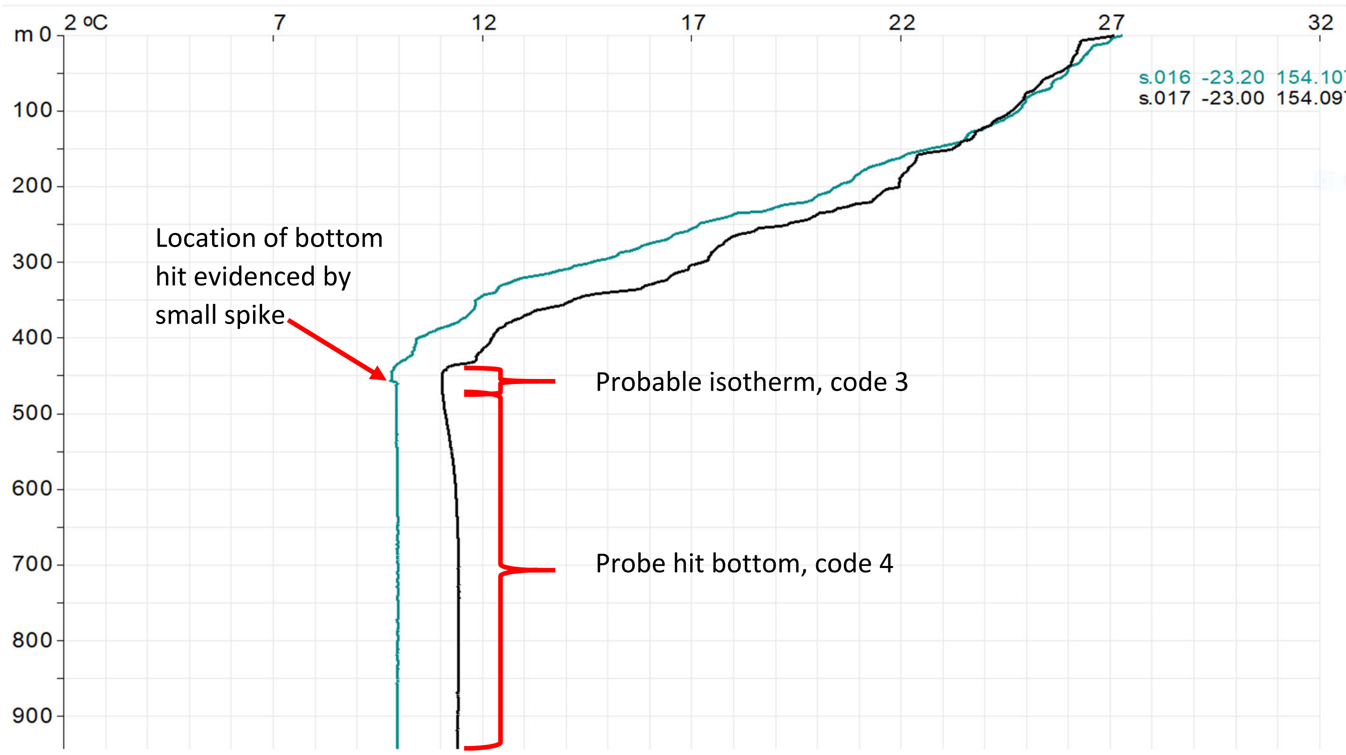


Hit Bottom - Code 4

When a probe hits the bottom the temperature trace usually goes isothermal. Contact with the bottom is often indicated by a small horizontal spike. Where there is an isothermal layer near the bottom and there is no spike, it can be difficult to ascertain the depth of the bottom hit, use bottom topography charts to help identify the correct depth.

Isotherm Bound vs. Bottom hit, Code 3 vs. Code 4

- Bottom hit is marked at the depth of the bottom hit and all depths deeper are marked code 4.
- Isotherm layer is marked at the start of the isotherm and labeled code 3 up to the point where the bottom depth is identified by bottom hit, and then below the bottom hit the flag is code 4.



14.5 Code 5 - The value was changed as a result of QC

Data Interpolated – Code 5

Where there is a very sharp spike over a small depth range (<10m) and the rest of the profile data otherwise appears good, the spike can be removed by interpolation.

- Interpolated data is marked at the start of the spike; the changed data interpolated over the spike is flagged code 5 and the data below the spike is flagged code 2.