APPLICATION NOTE NO. 82

Guide to Specifying a CTD

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CTDs are used to measure Conductivity (C), Temperature (T), and Pressure (P, but commonly written as D for depth). Parameters such as salinity, density, depth, and sound velocity can be calculated from these measurements.

When specifying a CTD, you must:

- Define your needs in terms of what parameters are to be determined
- Consider the conditions under which the measurements will be made
- Define the accuracy required in the basic measurements to meet the scientific or engineering objectives

The authoritative source of information regarding definition of oceanographic salinity and the derivation of oceanographic variables from the measured parameters of Conductivity, Temperature, and Pressure is The Practical Salinity Scale of 1978 (IEEE Journal of Oceanic Engineering, Vol. OE-5, No. 1, January 1980, page 14. Additional information is available in the following documents:

- UNESCO Technical Papers in Marine Science (No. 44) - Algorithms for Computation of Fundamental Properties of Seawater. You may obtain copies of this paper by contacting –
  Division of Marine Science
  UNESCO
  Place de Fontenoy
  75700 Paris, France
- Sea-Bird Application Note 14: 1978 Practical Salinity Scale

EVALUATING MANUFACTURER SPECIFICATIONS

I. Instrument (Sensor) Accuracy

Accuracy is generally understood as the ability of an instrument (sensor) to report the truth within a specified margin of error. The conditions under which a sensor’s measuring capabilities are judged are created during calibration by comparing the instrument reading with a reference of known accuracy during a period where the reference and sensor are both in equilibrium (i.e., static accuracy). The instrument’s response over the entire operating range is best judged by comparing responses at multiple points spanning the sensor’s measurement range. This allows instrument non-linearity to be identified and permits mathematical fitting (linearization of response) by application of calibration coefficients, thereby minimizing errors that might otherwise exist between the points observed during calibration. CTD manufacturers’ accuracy specifications are understood to be their claims for performance during initial calibration, unless specific explanation of a different meaning is provided.

II. Calibration Accuracy

The accuracy of a calibration is dependent on many factors, but primarily on the accuracy of the reference(s), the stability (degree to which it is unchanging) and homogeneity (degree of sameness at all points) of the test environment (i.e., bath), and the precision with which the comparisons are made. Given equal calibration accuracy, it is common to assume that two different instruments will perform equally well when used in the ocean. However, in a dynamic environment (e.g., profiling from a vessel) where several conditions are changing rapidly and simultaneously (temperature, conductivity, pressure, etc.), additional sources of error (dynamic error) reduce accuracy potential. **One cannot assume that equal calibration accuracy results in equal dynamic accuracy (i.e., the ocean is not a stirred bath).** Instrument and sensor design play a significant (and sometimes dominant) role in achievable dynamic accuracy.

III. Dynamic Accuracy

Simply stated, dynamic accuracy is calibration accuracy degraded by errors associated with instrument use which are not found in the calibration environment. The primary sources of dynamic errors in CTD measurements are:

- Turbulent wakes generated by the modulating effect of ship heave on the instrument motion through the water (known as *shed wakes*), causing contamination of temperature and conductivity measurements and resulting in *spiking* in salinity and density data.
- Unequal response times of Temperature and Conductivity (T & C) sensors.
- Measurements of T & C which are not well coordinated in time or space (i.e., measurements which are not made on exactly the same piece of water).
- Thermal mass error in conductivity cells.

These four factors account for the majority of error in CTD measurements and resulting salinity computation. The combined errors can range from many parts per million to many parts per thousand in severe conditions (e.g., 0.020 to 2.0 PSU Salinity).

If they cannot be nullified by instrument design and/or deployment methodology, the remaining secondary dynamic errors combined (e.g., viscous heating, pressure sensitivity, etc.) can induce salinity error ranging from approximately 0.005 to 0.020 PSU (5 to 20 parts per million).

Shed wakes affect all profiling CTDs that are lowered from vessels. In general, smaller CTDs have smaller wakes and the magnitude and duration of their errors are less than for larger CTDs, especially those integrated with water samplers. Other than size however, a CTD's design is not the cause of shed wake errors. Shed wake error is mentioned here because it is commonly unrecognized and often misinterpreted as CTD instrument error. Shed wake error is best minimized by:

- Careful physical arrangement of sensors on a given package to avoid (as much as possible) placement of the sensors where turbulent wakes are likely to exist.
- Modifying the winch operation (when possible) to suit the sea conditions, generally increasing descent rate as ship heave increases.

For best overall results, users should look for instruments that are delivered with high quality calibrations, and that have design features that minimize dynamic errors.

DESIGN FEATURES THAT CONTRIBUTE MOST TO SUPERIOR SALINITY ACCURACY

I. Establishing Response Times for Temperature (T) and Conductivity (C) Sensors

The accurate computation of Salinity requires that the temperature and conductivity (and pressure) of seawater be combined mathematically per PSS 78. If T and C sensors have the same response times and are physically co-located, the computation of salinity will be made correctly. As the response times are increasingly different, and as the salinity gradient in the ocean becomes larger, the salinity computations will contain error displayed as spikes in the plotted data. To the degree that sensor response times can be well matched, the potential for salinity accuracy is increased. Sea-Bird uses flow-controlled (pumped) sensors to control sensor response time.

Free-Flushed Sensors vs. Flow-Controlled (Pumped) Sensors

Of the three main parameters measured by all CTDs, conductivity is by far the most susceptible to error and is therefore worthy of the most attention. There are two types of conductivity sensors used on CTDs, electrode cells and inductive cells. In both types, the sensor response time is determined entirely by the flow rate through the cell (faster flow = faster response). As the flow rate through the cell changes, the response time also changes. Conductivity cells on free-flushed CTDs lowered from a vessel will experience continually changing flow rates, primarily resulting from ship heave and the decreasing lowering speed of the winch as successive layers of cable spooled off the drum reduces the drum diameter. In contrast, conductivity cells on flow-controlled (pumped) CTDs use a constant volume pump that delivers a constant flow rate to the cell, forcing a fixed response time that is completely independent of the CTD motion through the water. This causes a dramatic reduction in salinity spiking.

Temperature sensor response times are largely determined by their physical size and construction. However, flow rate does have an influence on their response time due to viscous heating. As water flows past the sensor, friction with the water causes a small amount of heat that causes an erroneously high reading of order 1-2 millidegrees C at 1 meter/second flow (varies with sensor design). This error cannot be avoided, and is significant for high accuracy salinity work. On free-flushed sensors where flow rates are constantly and unpredictably varying, the error cannot be removed from the data. In contrast, on flow-controlled CTDs, the error is a constant value and is easily removed from the data, based on physically defensible criteria. See Temperature Measurements in Flowing Water: Viscous Heating of Sensor Tips.

II. Coordinating T & C Measurements in Space and Time

CTDs with design features that match the time response of their T & C sensors, use flow control to keep those time responses constant under changing dynamic conditions, and make the measurements of T & C on exactly the same piece of water, have a fundamental advantage in determining accurate salinity. For example, Sea-Bird CTDs incorporate constant flow pumps and a device known as a T-C duct. The T-C duct is a essentially a small pipe inside of which the T and C sensors are positioned in line, and through which water is pumped at a constant rate. The chosen pump speed (flow rate) yields a conductivity response time equal to the temperature response time. The matched response times reduce salinity errors. The pump pulls water into the duct, forcing the measurement of T & C to be made on exactly the same water, despite any physical separation of the T & C sensors, CTD motion, or tilting of TS structure by internal waves. Because the temperature sensor is first in line ahead of the conductivity sensor, there is time delay between the T measurement and the C measurement associated with the transit time of a given piece of water through the duct. Since the flow rate is constant, the time delay is constant and is compensated by advancing the C measurement in time (via hardware or software) to correspond with the proper temperature measurement. See Application Note 38: Fundamentals of the TC Duct and Pump-Controlled Flow Used on Sea-Bird CTDs.

III. Minimizing Thermal Mass Errors in Conductivity Cells

Conductivity is a function of both temperature and salinity. The method by which conductivity cells are calibrated involves changing the temperature in a bath of a single salinity to yield a range of conductivities (e.g., from 2.6 S/m to 6 S/m between 1 and 32 °C at a salinity of approximately 35 PSU.). All conductivity cells have mass and therefore have the capacity to store heat. When a conductivity cell moves from warmer to colder water (for example, on the downcast), stored heat is lost to the surrounding water. Depending on cell design, varying amounts of that heat actually warm the water within the measurement area of the cell, changing (raising) its conductivity. Because CTD temperature sensors are not located inside the conductivity cell, the temperature (assumed accurate) reported by the CTD will be slightly different (lower) that the actual temperature inside the conductivity cell. As a result, when those measurements of T & C are used in the salinity equation, the computed salinity will be in error.

The amount of thermal mass error is a function of flow rate. The less time water resides inside the cell, the smaller the error, and vice versa. In controlled-flow CTDs, thermal mass error for a given system is predictable and can be minimized in data processing. In free-flushed CTD systems, the constantly varying flow rate in the cell makes it impossible to correct for thermal mass error.

A NOTE ABOUT PRESSURE SENSORS

Pressure sensor technology is sufficient in most CTDs to provide little contribution to salinity error. However, there can be significant differences in pressure sensor error from one manufacturer to another, based on their design, temperature compensation, and calibration. See Application Note 27Druck: Minimizing Strain Gauge Pressure Sensor Errors.

REFERENCES

Lueck, R.G. (1990) "Thermal Inertia of Conductivity Cells: Theory", JAOT V7(5), 741-755.
Morison, J. and R. Andersen, N. Larson (1993) "The Correction for Thermal-Lag Effects in Sea-Bird CTD Data", JAOT 1994, V11(4), 1151-1164

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