Technical Note

Characterizing Sensor Response Time

Benefits of using a TC Duct and Pump-Controlled Flow

April 2020

A 2-Box Model

Sensors do not react infinitely quickly to a new environmental condition. You can visualize this with a hypothetical 2-box ocean (Figure 1). In the model, all of the water in the top box is 20°C while the water in the bottom box is 0°C. Assume salinity is homogeneous across both boxes. If a profiling CTD descended from the top box to the bottom box, an ideal sensor would register the instantaneous change from 20° to 0 °C. Plotting these data would show a sharp horizontal drop in temperature and conductivity when the sensor passed from the top box to the bottom box. Furthermore, there would be no artificial spike in parameters like salinity and density that are derived from T and C measured by the sensors (Figure 2).

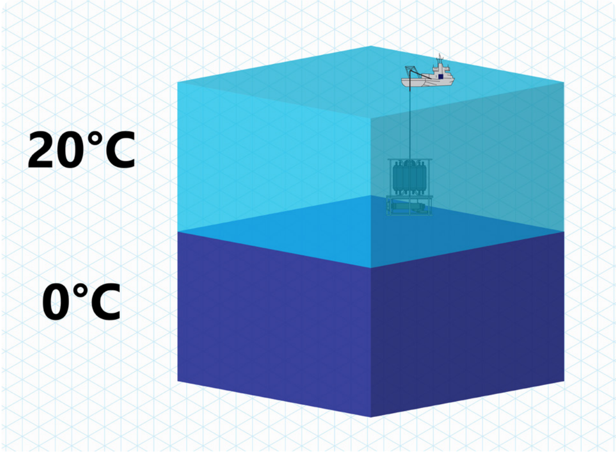


Figure 1: a 2-box temperature model

However, all real sensors have some degree of lag between their ideal and actual response, known as the sensor's response time. Plotting data at sharp gradients (such as the transition from the top box to the bottom box) reveals visible delays caused by the sensor's response time, where temperature and conductivity measured by the CTD takes time to "catch up" to the actual environmental change induced by the gradient. For calculated parameters, a mismatch in the conductivity and temperature response time generates an artificial spike, as each sensor "catches up" at different speeds, so mismatched values are used in the calculation of a single value (e.g. salinity or density).

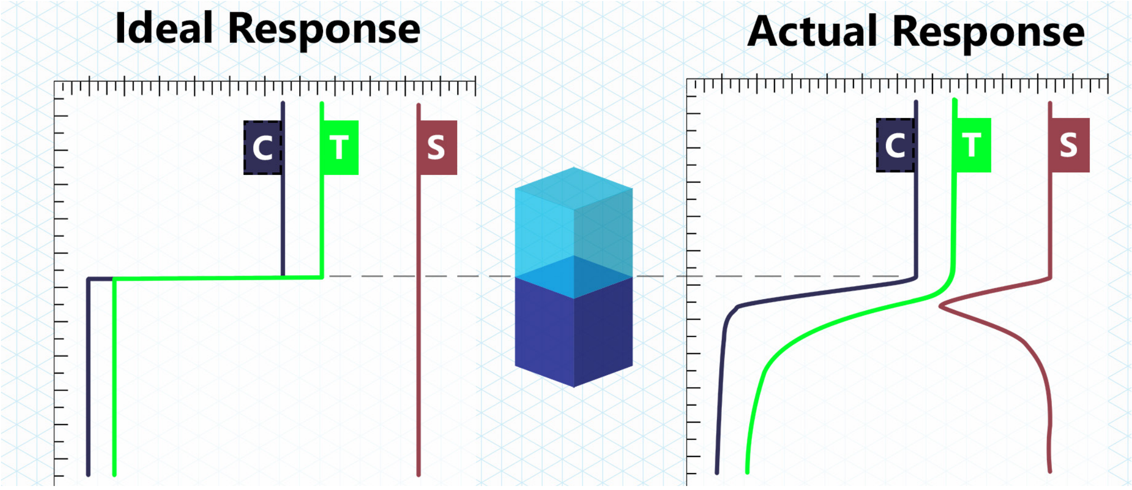


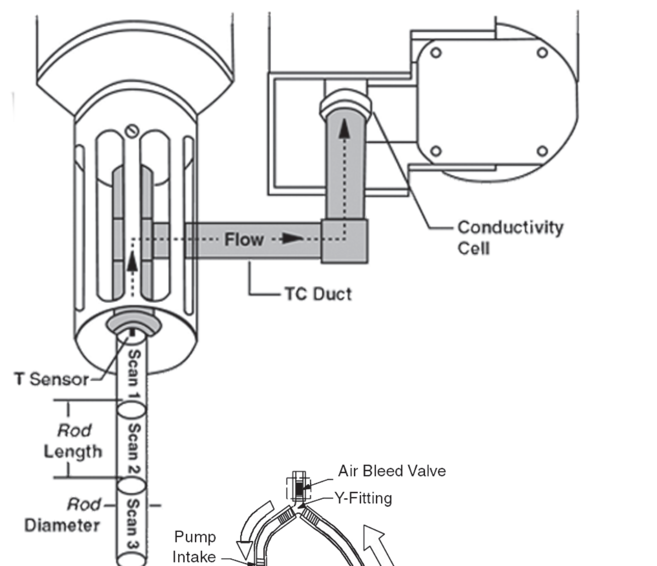
Figure 2: the ideal sensor response to a rapid temperature change (left) compared the a typical response (right)

Physically Controlling Response Time: TC Duct and Pump-Controlled Flow

Many CTD probes fail to measure C and T on the same water parcel because the C and T sensors are physically separated, or because the C and T sensors have different response times. Furthermore, the response time of their conductivity cells depends on the CTD drop rate, with more time required to fill the cells at slower speeds. Unless the CTD profiling speed is known and constant (it almost never is constant because of ship motion), the response time of these systems' conductivity cells will be continuously changing, and serious spiking will result.

To reduce salinity and density spiking to the lowest possible level without loss of resolution caused by data averaging, Sea-Bird Scientific uses a TC duct and a pump. These two features ensure that the measurement of temperature and conductivity are made on the same parcel of water as follows:

- **TC duct**: All the water sensed by both the temperature and conductivity cell must pass through a single small (0.4 cm) diameter opening.
- **Pump**: The electronically controlled pump forces the seawater to flow at a constant 30 cm^3/second to ensure that the C - T time responses are constant.



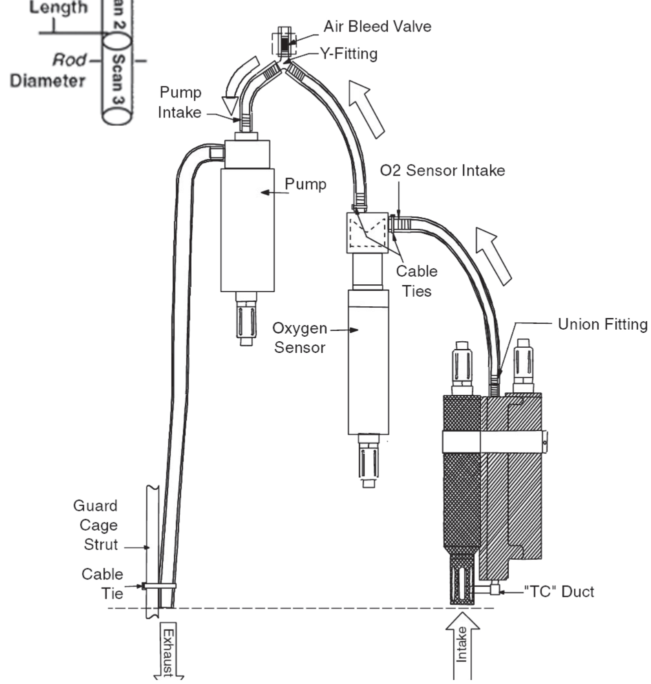


Figure 3 (top): A diagram of the TC duct
Figure 4 (bottom): A typical CTD flow path

The physical arrangement of the Sea-Bird T and C sensors with TC duct is shown in Figure 3.

1. As the CTD descends, water is taken in at the duct opening (the opening points downward) and its temperature is immediately sensed.
2. After a small time delay of 0.073 seconds during which the water flows through the duct, the water enters the conductivity cell. The 0.073-second delay is constant because the pumping speed is fixed.
3. This delay is automatically corrected in real-time by the SBE 11plus Deck Unit or afterwards in post-processing.

Note that the downward exhaust of the pumped water (Figure 4) eliminates any ram effect that would cause the flow rate to be affected by profiling speed.

The constant flow rate of the pump provides a consistent response time from the conductivity sensor, and the TC Duct provides a known delay between the temperature sensor and conductivity sensor.