Ocean Engineering 101

Considerations for CTD Spatial and Temporal Resolution on Moving Platforms

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When making measurements in a temporally and spatially variable marine environment, especially from a moving platform, instrument limitations in conjunction with the sampling methodology need to be considered when choosing the right tools for the measurements.

Oceanographic conductivity, temperature, and depth (CTD) instruments are used to collect high resolution data from stationary (moored observations) and moving platforms (shipboard profiling, towed vehicles, and AUVs). Obtaining accurate measurements is more difficult when moving either vertically (profiling) or horizontally (surface mapping), or both vertically and horizontally simultaneously (AUVs, towed vehicles). The combination of platform velocity, sensor response time, and instrument and platform data acquisition traits (including sampling frequency) all play a part in determining the quality and resolution of the final data set. For example, faster responding sensors allow for faster moving platforms, but are possibly limited by sampling frequency. Faster sampling frequency instruments also allow for faster moving platforms, but are possibly limited by sensor response time.

Many commercially available conductivity sensors specify response times dependent on flow rates past the sensor. For unpumped sensors, the flow rates can only be assumed from the transit speed of the package as it travels through the water. It is nearly impossible to achieve a constant velocity for a moving platform due to ship heave and accelerations, drift, and currents in the environment. Therefore, unpumped sensors can experience variable response times while in transit. This complicates post-processing of data and will result in uncorrectable, mismatched sensor measurements caused primarily by a response time disparity between temperature (not flow dependent) and conductivity measurements (flow dependent).

For these reasons, accurate and stable pumped CTD sensors that have very fast response times and that sample at rapid and constant frequencies are preferred. These CTDs offer the most flexibility in application and can accommodate most moving platform technologies.

Many platforms and/or applications require a smaller instrument, which usually has less sampling power than a larger CTD package can offer, including auxiliary sensors. For instance, towed platforms and slow moving AUVs, including gliders, utilize individual sensors or smaller "hand-held" CTDs with lower sampling frequencies and are sometimes equipped with slower response time sensors. Continuous sampling with an instrument that samples too slowly or has a response time inadequate for the speed of the vessel may result in a data set that lacks the resolution necessary to clearly map the attributes of interest. The "smoothed" result may appear as if a heavy-handed low-pass filter was applied to the data, potentially masking important yet smaller scale features. With unpumped sensors, the quality of the data is worsened and virtually uncorrectable due to variable speeds of the platform. To further complicate matters, some commercial gliders and AUVs do not acquire data at a constant sampling frequency, making it difficult to align data streams during post processing. All of these issues will restrict the spatial and temporal resolution in a moving application, even at speeds as slow as 1 m/s (2 knots). However, data can be greatly improved by pumping or by slowing the transit speed to give sensors time to respond.

As with temporal sampling, in order to resolve features with a spatial resolution of 1 m (for example), the sample rate and sensor response times must be adequate to resolve at least one-half the wavelength of the feature, in this case 0.5 m.

Table 1 provides simple examples of sensor response time and sampling frequency combinations with resultant realized spatial resolution for a towed undulating vehicle. The results provide an estimate of the maximum spatial resolution for an evenly spaced feature that can be expected given the combination of tow speed, sampling frequency and sensor response times. The true sampling resolution will likely be more complicated in reality, as gradient features in the marine environment are rarely evenly spaced. As can be surmised, moving faster with slower sampling instruments equipped with slower response time sensors will limit the accuracy and spatial reliability of a mapped data set.

To ensure the best data product for any project, it is important that the data quality objectives and the deployment method be compatible with the capabilities of the instrumentation.

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Limiting Sensor Response Time*	Instrument Sample Frequency *(delta t)*	Measurement Spatial Resolution	Realized Spatial Resolution (2X Measurement Resolution)
0.060 s	***8 Hz 0.125 s***	0.45 m	0.90 m
0.060 s	***24 Hz 0.042 s***	0.15 m	0.30 m
0.1 s	***1 Hz 1 s***	3.6 m	7.2 m
0.1 s	***4 Hz 0.25 s***	0.9 m	1.8 m
0.1 s	***8 Hz 0.125 s***	0.45 m	0.9 m
0.5 s	4 Hz 0.25 s	1.8 m	3.6 m
1 s	***1 Hz 1 s***	3.6 m	7.2 m
5 s	8 Hz 0.125 s	18.0 m	36 m
30 s	1 Hz 1 s	108.0 m	216 m
60 s (1 min)	8 Hz 0.125 s	216.0 m	432 m
180 s (3 min)	1 Hz 1 s	648.0 m	1296 m

* Assumes a constant flow rate past conductivity and oxygen sensors (i.e., steady response time)

Table 1. Sensor response time and sampling frequency combinations and expected spatial resolution. Results assume that the stated response times are met by the given suite of sensors, as in a pumped system or a constant tow speed application. Resolution estimates are for a towed instrument package that is moving through the water at a constant speed of 7 knots (3.6 m/s). Limiting factor noted in bold italics.