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Determining Sound Velocity from CTD Data

Use of CTD measurements to determine sound velocity is appealing because these instruments are simpler and more rugged, and because their resolution, accuracy, and stability lead to far better **precision** than can be obtained with direct SV measuring devices. For example, specifications of 0.01 mS/cm conductivity, 0.01 degrees C temperature, and 1 meter in depth are readily achieved with good quality CTD equipment. Assuming that the relationship between C, T, and D *and* SV is exactly known, the resulting uncertainty in SV would be as follows:

Error Type	Sound Velocity Error
temperature error of 0.01 deg C	0.021 meters/second
conductivity error of 0.01 mS/cm	0.011 meters/second
salinity error of 0.01 psu	0.012 meters/second
depth error of 1 meter	0.017 meters/second

The equivalent SV errors (considered at 15 degrees C, 42.9 mS/cm, 35 psu, and 0 pressure, i.e., typical open-ocean surface conditions) are much smaller than those usually claimed for direct-measurement instruments.

The question about the **absolute** accuracy of the inference of SV from CTD data is more difficult to answer. The main reason for this is apparently the result of differences in the instrumentation used by various researchers and is compounded by the difficulty of performing direct measurements of sound velocity under controlled conditions of temperature, salinity, and (especially) pressure. For example, three widely used equations (Wilson, 1960; Del Grosso, 1974; Millero and Chen, 1977) show differences in absolute sound speed on the order of 0.5 meters/second for various combinations of water temperature, salinity, and pressure, despite being based on careful measurements made under laboratory conditions.

The work of Millero and Chen is, however, the most modern, and it builds upon and attempts to incorporate the work of earlier investigators. Accordingly, the SV/CTD relationship described by these researchers in their paper of 1977 was used as a major component in the derivation of the Equation of State (UNESCO technical papers in marine science no. 44). Millero and Chen's 1977 equation is also the one endorsed by the UNESCO/SCOR/ICES/IASPO Joint Panel on Oceanographic Tables and Standards, which comprises the internationally recognized authority for measurements of ocean parameters (in Sea-Bird Scientific's Seasoft software, users may select any of the 3 equations mentioned above).

Pike and Beiboer, 1993, made a careful comparison of algorithms used to calculate sound velocity. They concluded that use of the Wilson equation should be discontinued, and that the Chen and Millero algorithm should be used on the continental shelf while the Del Grosso formula is more appropriate for deep ocean waters and long path lengths. Their paper includes tables showing valid temperature and salinity ranges for each of the algorithms.

We draw the following conclusions from the research papers listed above:

1) Investigators using specialized equipment under scrupulously controlled laboratory conditions report measurements of SV vs. changes in temperature, salinity, and pressure which differ by 0.5 meters/second and more. *It is unrealistic to expect that commercial direct-measurement instruments will be more accurate under field conditions than the laboratory equipment used by successions of careful researchers.*

2) The claimed *accuracy* of commercial direct-measurement SV probes probably more legitimately represents their *precision* (compare with CTD/SV uncertainties tabulated above) rather than their absolute accuracy. The relationship between what these instruments read and true sound velocity is probably just as dependent on the same vagaries that are also the only significant sources of error when employing the CTD approach.

3) Because of the uncertainties in the time-delays associated with the acoustic transducers and electronics (and because of the difficulty of measuring with sufficient accuracy the length of the acoustic path), direct-measurement probes must be calibrated in water. As suggested by the research under controlled laboratory conditions, this is not an easy task, especially over a range of temperature, pressure, and salinity. On the other hand, a CTD probe can easily be calibrated using accepted methods.

4) A CTD can predict **absolute** SV to something better than 0.5 meters/second (a judgment seconded by Professor Millero in a private conversation), while its **relative accuracy** (precision) is probably better than 0.05 meters/second under the most demanding conditions of field use.

5) The very high precision associated with CTD measurements and the existence of an internationally accepted relationship (even if imperfect) between CTD and SV permits very consistent intercomparison and a high degree of uniformity among CTD-derived SV data sets, no matter when and where taken.

Bibliography

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