An Evaluation of Expendable Salinity-Temperature Profilers in the Eastern North Pacific

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11 June 1979 and 18 April 1981

ABSTRACT

Vertical profiles from expendable conductivity-temperature (XCTD) and sound velocity-temperature (XSVT) instruments are compared with simultaneous profiles sampled with Guildline CTD and Plessy CTD-SV systems. From these comparisons the estimated accuracies of these instruments are 0.08°C for the XCTD and 0.03°C for the XSVT in temperature, and 0.13‰ for the XCTD and 0.18‰ for the XSVT in salinity. These measurement errors are compared to the locally observed upper ocean variability.

1. Introduction

The need for routine ocean monitoring along with the requirements for rapid synoptic surveys has led to the increased application of expendable technology in physical oceanography. Use of the familiar expendable bathythermograph (XBT) has yielded a large amount of valuable temperature data over the recent past. Many investigators have realized that the signal they want to measure is much larger than the modest accuracy of an XBT.

In many parts of the ocean, however, temperature structure alone is not sufficient to study the ocean's variability. In most of these regions knowledge of the vertical salinity structure is equally important. It would be useful if a reliable expendable salinity-temperature profiler were available for oceanographic sampling. This study reports on a field intercomparison between the presently available expendable salinity profilers and simultaneous reference profiles recorded with a Guildline CTD. The observations were collected in the northeast Pacific.

2. Expendable instruments tested

The expendable sensors evaluated in this experiment were the XSVT manufactured by Sippican Co., Marion, Massachusetts (Ref. Manual, 1978) and the XCTD manufactured by Grundy Environmental

0022-3670/81/081159-07$05.75

TABLE 1. Temperature intercomparison data. G: Guildline, U: USN, P: Plessey, S: Sippican and D: DREP.

Depth (m)	$\bar{T}_G$ (°C)	$\Delta T/\Delta Z$ (°C m^{-1})	Difference of mean (°C)				Standard deviation (°C)				
			$\bar{U}-\bar{G}$	$\bar{P}-\bar{G}$	$\bar{S}-\bar{G}$	$\bar{D}-\bar{G}$	σ_G	σ_U	σ_P	σ_S	σ_D
0	14.94	0	−0.020	0.344	0.070	−0.193	0.030	0.012	0.054	0.029	0.048
20	14.63	−0.015	0.250	0.500	0.318	0.015	0.432	0.058	0.077	0.054	0.160
40	11.23	−0.170	0.991	1.057	1.590	1.015	0.682	0.512	0.504	0.488	0.292
60	8.82	−0.121	0.434	0.357	0.549	0.318	0.143	0.179	0.276	0.252	0.366
80	7.70	−0.056	0.167	0.197	0.200	0.147	0.132	0.098	0.144	0.169	0.196
100	7.06	−0.032	0.111	0.162	0.132	0.092	0.111	0.082	0.118	0.122	0.133
150	6.29	−0.015	0.015	0.121	0.040	−0.029	0.022	0.028	0.078	0.036	0.048
200	5.85	−0.009	0.034	0.064	0.053	−0.036	0.065	0.083	0.101	0.073	0.059
250	5.27	−0.012	0.044	0.035	0.023	−0.067	0.090	0.087	0.113	0.078	0.061
300	4.81	−0.009	0.071	0.062	0.043	−0.036	0.086	0.070	0.099	0.071	0.046
400	4.30	−0.005	0.042	0.066	0.024	−0.050	0.049	0.035	0.094	0.055	0.025
500	4.03	−0.003	0.023	0.085	0.030	−0.066	0.037	0.027	0.097	0.042	0.015
600	3.82	−0.002	0.008	0.086	0.031	−0.064	0.021	0.009	0.097	0.037	0.013
700	3.64	−0.002	0.003	0.104	0.041	−0.059	0.018	0.022	0.111	0.035	0.012

Systems (formerly Plessey), San Diego, California (Ref. Manual, 1977). The former does not measure electrical conductivity; instead salinity is inferred from measurements of sound velocity and temperature (Emery, 1977). In this probe, sound velocity is measured over a 5.2 cm water path using a sing-around frequency.[1] Sound velocity is translated to an FM signal which is transmitted up the two-wire link. Temperature, sensed by a standard XBT thermistor, is transmitted as the resistance between the two wires. Field data were recorded on casette tapes by Sippican personnel; subsequent translation to 9-track digital tapes by Sippican was required. It should be noted that this was a developmental product and not a proven, off-the-shelf device.

The Grundy (Plessey) XCTD, however, is a product presently on the market. The conductivity cell consists of a 6 mm (I.D.) glass tube with three electrodes. The conductivity bridge circuit generates an FM signal; the thermistor circuit produces another FM signal. Both of these are telemetered to the surface with a two wire system. The Plessey (hereafter this system will be referred to as Plessey rather than Grundy) data logger uses an analog circuit to compute salinity which is displayed on a chart, along with temperature, as a function of time (depth). Simultaneously digital values of conductivity, temperature and time are recorded on 9-track magnetic tape. The analog traces were of low quality, due to the poor response of the chart recorder, and the digital tape was badly formated leading to significant processing difficulties.

3. Reference profilers and their calibration

No instrument can be absolutely accurate; however, a well-calibrated, carefully maintained, modern CTD should be an order of magnitude more accurate than the expendable sensors. We chose the Guildline CTD (Model 7800) as a primary standard and the Plessey CTD-SV (Model 9050) maintained by the U.S. Naval Ocean Systems Center (NOSC), San Diego (herein this system is referred to as USN), as the secondary standard.

Prior to the field experiment, both reference CTD systems were shipped to the Northwest Oceanographic Calibration Center in Seattle. The calibrations for both instruments were staged as closely as possible in both time and conditions. The results indicated that both CTD's deviated from a reference temperature by 0.03°C. For salinity the Guildline CTD deviated from the standard by 0.02‰ while the maximum deviation between the two CTD systems was 0.04‰.

At this time the Plessey Sound Velocity (SV) sensor was also calibrated. Sound velocity was calculated from the reference temperatures and salinities using Del Grosso's (1974) equation. Maximum deviations of 0.2 m s^{-1} were found between the Plessey SV readings and these reference sound velocities. In the analysis of the field experiment the reference sound velocity profiles were computed from the Guildline CTD measurements again using Del Grosso's equation.

4. Field experiment

The intercomparison experiment was staged along a line from Victoria, B.C. to ocean weather station PAPA (50°N, 145°W). West of 129°W the degree of inhomogeneity (or the abundance of frontal structure) is known to be greatly reduced. Two locations (along this line) named NSI (49°24′N, 133°25.2′W) and LP07 (49°10′N, 132°40′W) were selected for intensive intercomparison. At each site 36 expendable sensors of each type were released (by representatives of the respective manufacturers) while the ship

[1] Sing-around frequency is determined by the transit time of sound through seawater between transducers.

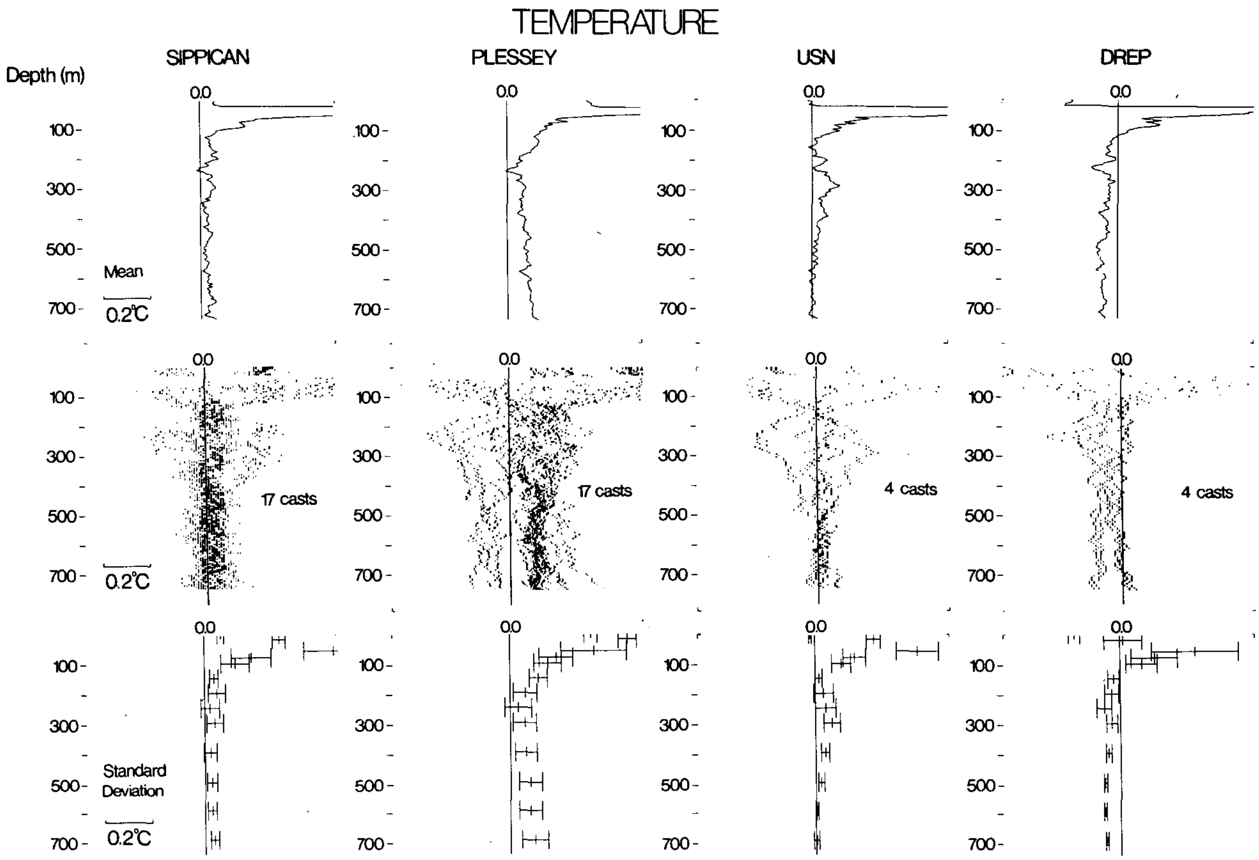

FIG. 1. Intercomparison of temperature data at stations LP07 (49°10′N, 132°40′W) and NSI (49°24′N, 133°25.2′W). Sensors used were Guildline (CTD Model 7800), Sippican (XSVTD Model R-8691), Plessey (Grundy XCTD Model 9090), USN (Plessey CTD-SV Model 9050) and DREP (Ramsay MK1 Sound Velocimeter).

was drifting. During this time the Guildline and Plessey CTD systems were used alternatively to obtain, as rapidly as possible, profiles down to 750 m. Winch speeds were 1 m s^{-1} for the Guildline and 0.5 m s^{-1} for the Plessey system.

5. Depth-time relationships

Both expendable sensors do not directly measure depth (or pressure) but rather infer it from the transit time. Plessey recommends a constant fall rate of 6.1 m s^{-1} for their XCTD while Sippican provided us with the formula

$$\text{Depth (m)} = 5.8t - 0.005t^2, \qquad (1)$$

where t is transit time in seconds. Data presented in this paper were processed with these depth-time relationships.

6. Intercomparisons

In the following comparisons all the data from both sets of 36 casts were combined. Individual expendable profiles were differenced from the corresponding Guildline profile and the differences lumped together as a statistical example. In the figures these data are presented as a mean difference for the instrument (top), scatter plots of all casts (middle) and standard deviations approximately every 20 m (bottom). In these presentations DREP (D) represent profile measurements made by the Canadian Defense Research Establishment Pacific with a Ramsay MKI Sound Velocimeter.

a. Temperature

As can be seen in Table 1 and Fig. 1 the two reference CTD systems compared very well. For the expendables the Sippican XSVT appears to have a relatively small (~0.03°C) and fairly uniform mean difference from the Guildline. The XSVT standard deviations were also similar to those of the Guildline.

Temperatures from the Plessey XCTD exhibited slightly larger mean differences from the Guildline reference especially in the upper 200 m. Plessey standard deviations were consistently higher than other sensors and appeared to increase with depth. It should be noted that all deviations were less than the maximum of 0.3°C specified by both manufacturers.

TABLE 2. Conductivity intercomparison data. G: Guildline, U: USN, and P: Plessey.

Depth (m)	$\bar{C}_G$ (mmho cm^{-1})	$\Delta C/\Delta Z$ (mmho cm^{-1} m^{-1})	Difference of mean (mmho cm^{-1})		Standard deviation (mmho cm^{-1})		
			$\bar{U} - \bar{G}$	$\bar{P} - \bar{G}$	σ_G	σ_U	σ_P
0	39.93		−0.069	0.128	0.034	0.021	0.097
20	39.66	−0.013	0.204	0.343	0.325	0.108	0.138
40	36.82	−0.142	0.780	0.875	0.545	0.414	0.400
60	34.80	−0.101	0.313	0.315	0.130	0.131	0.247
80	33.91	−0.044	0.096	0.198	0.106	0.069	0.137
100	33.54	−0.018	0.043	0.187	0.075	0.050	0.106
150	33.43	−0.002	−0.018	0.185	0.015	0.021	0.090
200	33.31	−0.002	0.013	0.130	0.053	0.058	0.113
250	32.85	−0.009	0.036	0.114	0.077	0.070	0.111
300	32.49	−0.007	0.056	0.146	0.072	0.056	0.105
400	32.16	−0.003	0.034	0.168	0.034	0.021	0.097
500	32.05	−0.001	0.018	0.187	0.025	0.022	0.091
600	31.97	−0.001	0.011	0.191	0.014	0.008	0.093
700	31.92	−0.001	0.010	0.203	0.015	0.019	0.091

b. Conductivity

Conductivity was measured by the Guildline and USN CTD's, and by the Plessey expendable XCTD. As shown in Table 2 and Fig. 2 the differences between the two reference CTD's appear randomly distributed with a maximum of 0.18 mmho cm^{-1} below 500 m. The differences between the Guildline and the XCTD, however, exhibit a strong positive bias with large differences at the surface, a minimum difference at ~200 m and a subsequent increase with depth. Again Plessey XCTD standard deviations were relatively high.

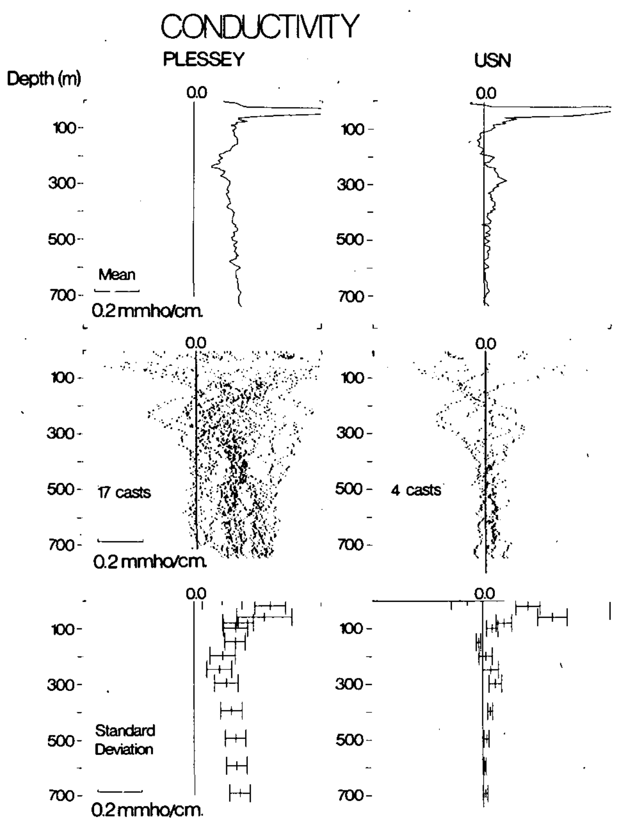

FIG. 2. Intercomparison of conductivity data at stations LP07 (49°10′N, 132°40′W) and NSI (49°24′N, 133°25.2′W). Sensors used were Guildline (CTD Model 7800), Plessey (Grundy XCTD Model 9090) and USN (Plessey CTD-SV Model 9050).

c. Salinity

Salinity can be computed from either conductivity and temperature or sound velocity and temperature. For the conductivities recorded by both the reference CTD's and the XCTD, salinity was computed using the equation in Ribe-Howe (1975) (see also Lewis and Perkin, 1978). For sound velocity Del Grosso's (1974) sound velocity equation was inverted to solve for salinity knowing sound velocity, temperature and depth (Emery, 1977).

Using the Guildline as the primary reference differences were computed for all sensors (Table 3, Fig. 3). As expected differences between the reference CTD's were very small with a slight negative bias (~ −0.05‰) near the surface.

The mean differences for the Plessey XCTD have a positive bias which increases with depth to values > 0.1‰. Standard deviations for the XCTD system also increase with depth unlike the reference values. The clusters of profiles in the scatter presentations suggest that sensor accuracy may be a function of the component's production lots.

The mean differences for the Sippican expendable were slightly larger than for the Plessey XCTD with maximum values > 0.2‰. Standard deviations were uniformly large (~0.12‰) over the water column. The scatter plots showed no tendency to cluster but instead exhibited a wide spread for all depths.

TABLE 3. Salinity intercomparison data. G: Guildline, U: USN, P: Plessey, S: Sippican and D: DREP.

Depth (m)	$\bar{S}_G$ (‰)	$\Delta S/\Delta Z$ (‰ m^{-1})	Difference of mean (‰)			Standard deviation (‰)			
			$\bar{U}-\bar{G}$	$\bar{P}-\bar{G}$	$\bar{S}-\bar{G}$	σ_G	σ_U	σ_P	σ_S
0	32.36		−0.049	−0.170	−0.191	0.013	0.013	0.128	0.123
20	32.35	0.000	−0.019	−0.099	0.003	0.070	0.076	0.114	0.141
40	32.57	0.011	−0.065	−0.072	−0.007	0.083	0.078	0.117	0.162
60	32.70	0.006	−0.073	0.001	0.107	0.021	0.040	0.103	0.152
80	32.79	0.005	−0.054	0.027	0.130	0.021	0.022	0.101	0.120
100	32.99	0.010	−0.060	0.050	0.109	0.041	0.035	0.118	0.130
150	33.59	0.012	−0.033	0.088	0.137	0.029	0.045	0.122	0.114
200	33.86	0.006	−0.017	0.084	0.178	0.012	0.023	0.115	0.117
250	33.90	0.001	−0.003	0.097	0.214	0.006	0.010	0.119	0.129
300	33.93	0.001	−0.003	0.110	0.195	0.007	0.010	0.123	0.127
400	34.01	0.001	−0.002	0.132	0.209	0.013	0.013	0.128	0.123
500	34.10	0.001	0.002	0.136	0.200	0.011	0.008	0.134	0.125
600	34.19	0.001	0.005	0.139	0.179	0.007	0.007	0.139	0.131
700	34.26	0.001	0.009	0.135	0.166	0.005	0.005	0.146	0.138

d. Sound velocity

Using sound velocities computed from the Guildline CTD profiles differences were formed for the XSVT, the Plessey CTD-SV and the DREP instruments (Table 4, Fig. 4). Again the agreement with the USN reference is very good. The Sippican expendable also compares fairly well with a difference of ~3.5 m s^{-1} below 150 m. There appears to be a slight positive bias in the XSVT. The DREP

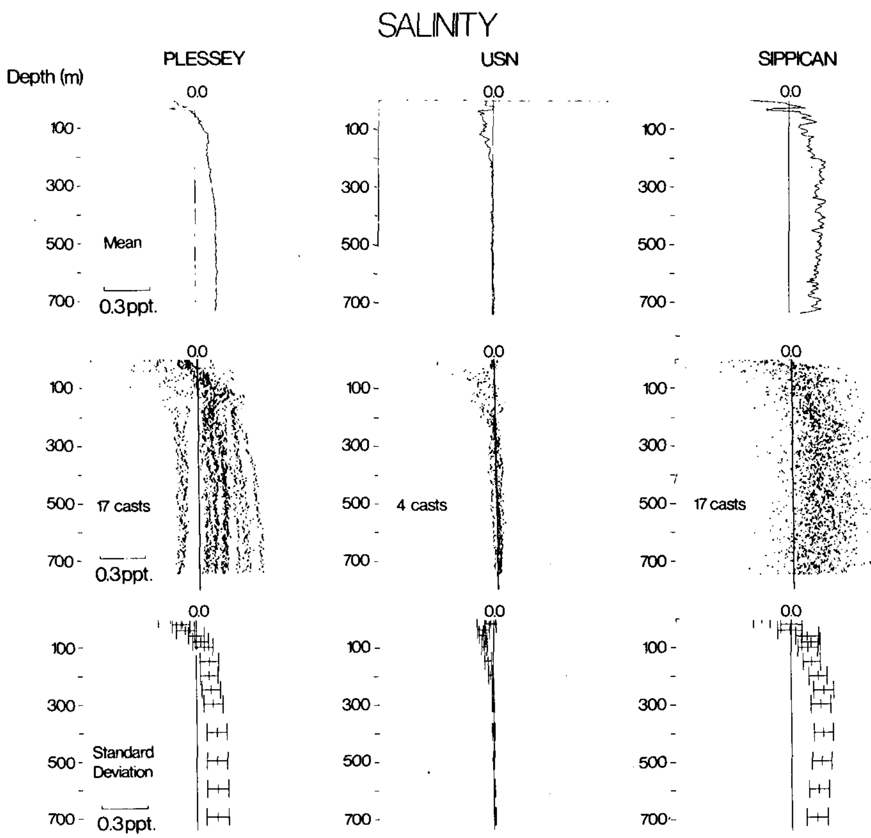

FIG. 3. Intercomparison of salinity data at stations LP07 (49°10′N, 132°40′W) and NSI (49°24′N, 133°25.2′W). Sensors used were Guideline (CTD Model 7800), Plessey (Grundy XCTD Model 9090), USN (Plessey CTD-SV Model 9050) and Sippican (XSVTD Model R-869). Values are given in parts per thousand (ppt).

TABLE 4. Sound velocity intercomparison data. G: Guildline, U: USN, S: Sippican and D: DREP.

Depth (m)	$\overline{SV}_G$ (m s^{-1})	$\Delta SV/\Delta Z$ (m s^{-1} m^{-1})	Difference of mean (m s^{-1}) $\bar{U}-\bar{G}$	$\bar{S}-\bar{G}$	$\bar{D}-\bar{G}$	Standard deviation (m s^{-1}) σ_G	σ_U	σ_S	σ_D
0	1503.40		−0.035	0.358	−0.321	0.191	0.121	0.089	0.120
20	1502.72	−0.034	0.721	1.038	0.663	1.378	0.259	0.067	0.153
40	1491.75	−0.548	2.835	5.438	3.818	2.228	1.553	1.571	0.983
60	1483.60	−0.408	1.087	2.153	0.940	0.529	0.594	0.889	0.407
80	1479.82	−0.189	0.307	0.924	0.257	0.491	0.351	0.617	0.107
100	1477.92	−0.095	0.162	0.645	0.066	0.394	0.274	0.404	0.170
150	1476.48	−0.029	−0.111	0.331	−0.339	0.064	0.060	0.080	0.109
200	1475.89	−0.012	−0.038	0.428	−0.288	0.254	0.306	0.309	0.110
250	1474.42	−0.029	0.015	0.362	−0.438	0.361	0.331	0.345	0.087
300	1473.39	−0.021	0.123	0.412	−0.321	0.348	0.270	0.308	0.111
400	1473.03	−0.004	0.021	0.358	−0.321	0.191	0.121	0.229	0.115
500	1473.68	0.007	−0.052	0.366	−0.411	0.142	0.104	0.154	0.117
600	1474.53	0.008	−0.107	0.353	−0.405	0.082	0.035	0.106	0.125
700	1475.52	0.010	−0.122	0.380	−0.390	0.076	0.086	0.139	0.112

measurements exhibited a negative bias for the mean about the same size as the XSVT.

7. Local variability

In order to evaluate the utility of the expendable sensors tested, one must have some knowledge of the oceanic variability they must measure. In Fig. 5 the parameter profiles from six Guildline casts are presented both as scatter diagrams and as standard deviations. Four of the casts are from LP07 while two are from NSI.

From these measurements it can be estimated that

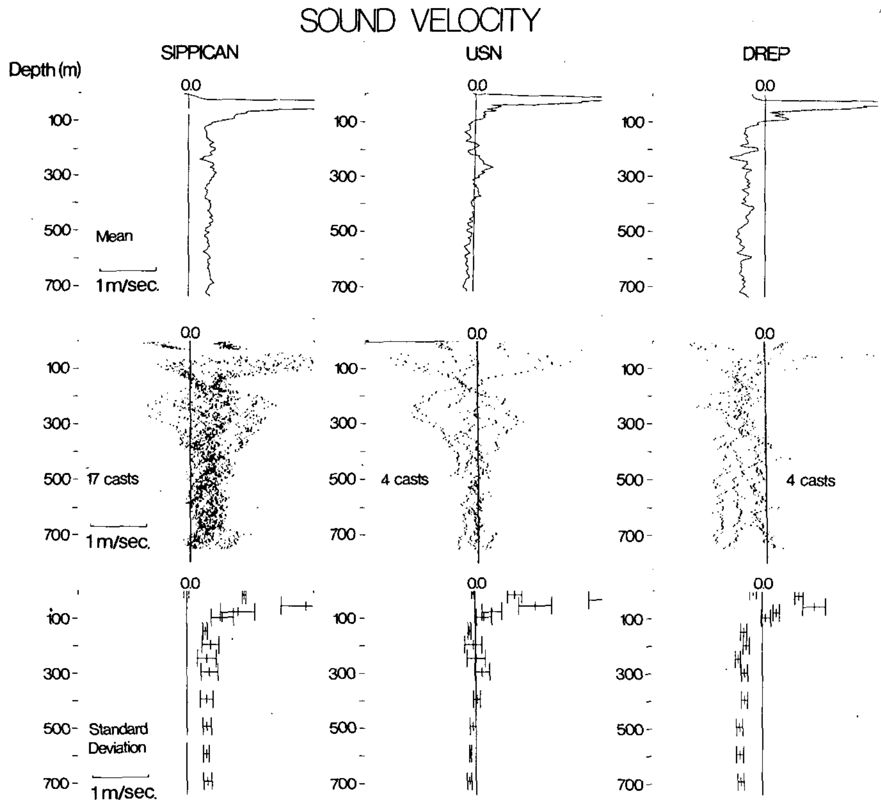

FIG. 4. Intercomparison of sound velocity data at stations LP07 (49°10′N, 132°40′W) and NSI (49°24′N, 133°25.2′W). Sensors used were Guildline (CTD Model 7800), Sippican (XSVTD Model R-869), USN (Plessey CTD-SV Model 9050) and DREP (Ramsay MKI Sound Velocimeter).

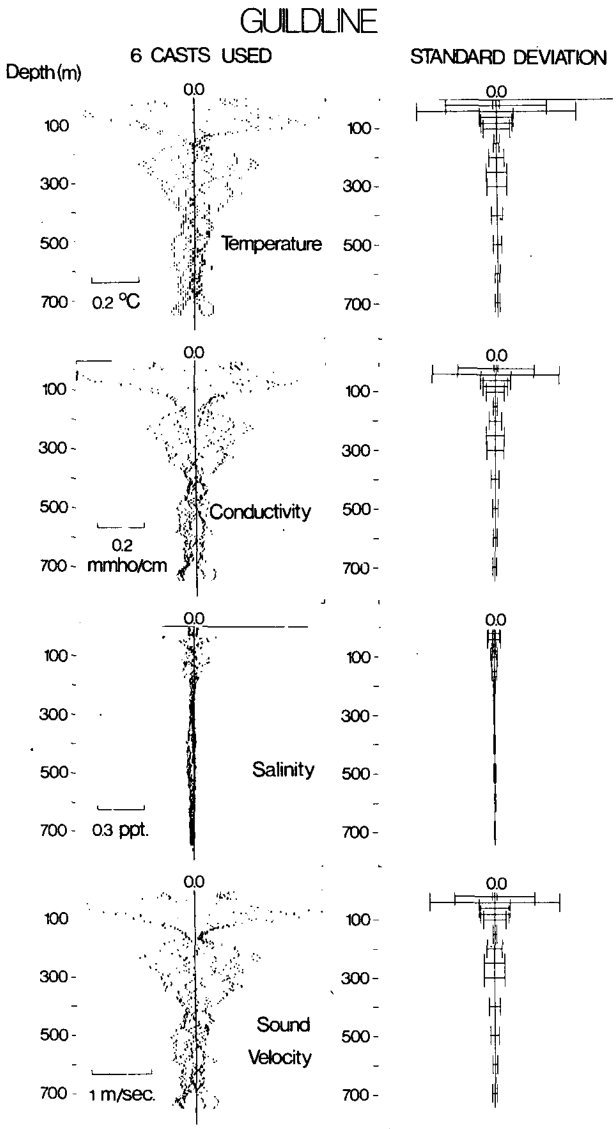

FIG. 5. Difference from mean of individual Guildline CTD (Model 7800) casts made at station LP07 (49°10′N, 132°40′W) and NSI (49°24′N, 133°25.2′W).

the temperature fluctuations are ~0.2°C, greater than the ~0.1°C differences for both expendables (Table 1). Salinity variations, however, (Fig. 5) are ~0.1‰ which is about the same size as (or smaller than) the differences calculated for the expendables (Table 3).

8. Probe failure

The intercomparison results presented here were all taken from a drifting ship. A problem with this procedure was the possible fouling of the expendable wire on the ship or CTD cable. Of the 72 expendable casts made for each company only 17 were considered good enough to be examined. Unusable casts contained obvious errors due to wire fouling. A series of casts made later, with the ship underway, yielded much lower failure rates with six out of 23 Sippican XSVT's failing and three out of 21 Plessey XCTD's failing.

9. Summary

Comparisons between expendable profilers and reference CTD casts indicates that expendables can measure temperature to within 0.1°C and salinity to within 0.2‰. Standard deviations (precision) in salinities are also ~0.2‰. This may be adequate for many oceanographic applications where the salinity signal is large in space or time. Improvements by manufacturers, especially in the calibration of their probes, may lead to routine salinity profiles accurate within 0.05–0.1‰.

At present, data logging systems are the major problem in using the available systems. Much development work is needed to produce a reliable and simple-to-use data recording package. Improvements may also come in a better evaluation of the recommended fall rate used by the manufacturers.

Acknowledgments. The authors would like to thank those scientific personnel (13 persons) who participated in the field program representing the Institute of Ocean Sciences, Offshore Group, Defense Research Establishment Pacific, and the Sippican and Grundy Companies. Data analysis was the responsibility of D. Harrington of U.B.C. This activity was supported by a grant from ONR Code 481, at U.B.C. (NRO83-207), NOSC and Texas A & M. Cooperation and support of NORDA Code 500 through a research and development contract to Sippican is also acknowledged.

REFERENCES

Del Grosso, V. A., 1974: New equation for speed of sound in natural waters (with comparisons to other equations). *J. Acoust. Soc. Amer.*, **56**, 1084–1091.

Emery, W. J., 1977: The errors involved in inferring salinity from sound velocity. *J. Phys. Oceanogr.*, **7**, 293–297.

Lewis, E. L., and R. G. Perkin, 1978: Salinity: Its definition and calculation. *J. Geophys. Res.*, **83**, 466–478.

Plessey Environmental Systems, 1977. Instruction Manual: Model 9090 Expendable S/T/D (XSTD) System.

Ribe, R. L., and J. G. Howe, 1975: An empirical equation relating seawater salinity, temperature, pressure and electrical conductivity. *Mar. Tech. Soc.*, **9**, 3–13.

Sippican Ocean Systems, 1978. Descriptive Report: R-869 Expendable Sound Velocimeter.