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Test and Evaluation of SBE Model 16 Conductivity / Temperature Recorder

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ABSTRACT

An evaluation resulting from preliminary testing of four stationary conductivity/temperature recorders is presented. The recorders are intended for use in moored time series operations. A number of local test deployments were made to evaluate instrument performance by comparing their data records and noting changes in their operation over time. Very few operational problems were encountered during the testing series. Salinity data quality was shown to be contingent upon the condition of the instrument's conductivity cell. Impurities in the conductivity cell caused lower salinity values in the time series but temperature data were unaffected. The implications of this finding remain in question since it is believed that the testing site is subjected to more sources of possible cell contamination than would be encountered at an offshore deployment location. Considerations for future offshore moored applications are identified. Instrument specifications and test deployment design are also discussed.

INTRODUCTION

In 1990 the Fisheries Oceanography Investigation of the Northeast Fisheries Science Center purchased four model 16 conductivity/temperature recording instruments from Seabird Electronics, Inc. (SBE). From July 1990 to February 1991, six short test deployments were conducted to evaluate their operation before they were to be used offshore. The four recorders were purchased over a time period of nearly ten months and as a result, only two of the six test deployments were carried out using all four instruments (See Table 1). The greater part of the following discussion is devoted to these latter two tests. Throughout the text, each instrument is referred to by its manufacturer's serial number (#359, #365, #561, #595).

During the early evaluation tests, it was discovered that the fouling of the conductivity cell would be an important consideration for ensured data quality. Additional testing became necessary to determine how effectively fouling could be controlled using antifoulant caps designed to fit onto the conduc-

Table 1. Summary of NEFSC dock test deployments conducted since July, 1990. The Seacats are identified in the text by their serial numbers.

Test	Date	Instruments Used (serial number)	Sampling Rate	Duration in Water (approximate)
1	July 18-20	359	1/60 sec	46 hr
	1990	365	1/60 sec	46 hr
2	Aug 20-21	365	1/60 sec	16 hr
	1990	561	1/60 sec	16 hr
3	Sept 11-24	365	1/5 min	13 days
	1990	561	1/5 min	13 days
4	Dec 7, 1990-	365,561	1/5 min	23 days
	Jan 2, 1991	359,595	1/5 min	23 days
5	Jan 29-31	561,595	1/60 sec	15 hr
	1991	*Profiler* 360	1/60 sec	15 hr
6	Feb 14-28	365,561	1/5 min	14 days
	1991	359,595	1/5 min	14 days

tivity cell ends. Preliminary results from the test and evaluation program are presented in this report.

DESCRIPTION OF INSTRUMENTS

The SBE *Seacat* model 16 is designed to be moored for an extended time period recording conductivity and temperature values at a known sampling rate. The instrument's cylindrical plastic housing measures approximately 16 in. long and 4 in. in diameter. The sensor unit, comprised of a *Pyrex* conductivity cell and pressure protected thermistor, is horizontally mounted onto the upper end of the housing to allow for regular tidal flushing of the unit. The sensors are protected from physical damage by an aluminum cell guard. The thermistor will record temperature values from -5.000 to +35.000 °C and with an accuracy of ±0.01 °C per 6 months. Salinity data may be acquired from 0.000 psu to ≈39.000 psu with an approximate accuracy of ±0.01 psu per month.

The *Seacat* is powered with six D-cell (alkaline) batteries which are loaded by unscrewing the bottom end cap of the housing. An internal lithium back-up battery source is capable of performing all *Seacat* functions and will preserve data in memory for up to two years in the event the main battery supply falls below a 5.7 volt operating threshold. The *Seacat* main power supply is sufficient to fill the entire 256K memory allowing for storage of approximately 65,000 conductivity/temperature values. Depending on sampling rate, it may be deployed for as long as a year and at a maximum depth of 600 m. Data logging can be preset to any date and integer hour and, if desired, the sampling interval may be changed for up to as many as nine prelogged dates and times. The *Seacat* has a claimed timing precision of ±3 min. per year.

Communication with the *Seacat* for initial set up and data retrieval instructions is via a RS-232C cable link. The latter is plugged into a 4 pin I/O cable connector, located beside the Seacat cell guard, and into the serial port of an IBM PC/XT/AT or compatible computer.

TEST PROCEDURE

The primary aim of the testing program was to evaluate the instruments for their data quality, ease of use, and reliability. This was done with side-by-side tests (refer to Figures 1 and 2). A secondary aim was to obtain a data set with two instruments separated vertically. The latter imitated the intended use of the recorders on a mooring to measure the development of stratification in the water column. Due to instrument failure (#359) and strong tidal mixing in the test area, a data set satisfying the secondary objective was not obtained. As a result, only the six side-by-side tests will be discussed (see Table 1).

TEST 1

In the first test *Seacat* #359 and #365 were braced side-by-side with their sensor units parallel and hung from the National Marine Fisheries Service (NMFS) dock approximately 1 to 2 m, depending on the tide, below the surface of the water (Figure 1). The *Seacats* recorded in the water for ≈46 hours at a sampling rate of 1 scan per minute. A "scan" is a simultaneous observation of conductivity and temperature recorded by the *Seacat*. A number of water samples were taken using a Niskin bottle at nearly even intervals during each side-by-side test for salinity data quality control. Because the duration of the side-by-side tests varied, the number of water samples taken was not the same for each test. The sample time was chosen to coincide with the time the *Seacats* recorded a scan so that the water sample salinity could later be referenced against a particular *Seacat* salinity value. The water samples were analyzed using an *Autosal Salinometer*. *Seacats* #359 and #365

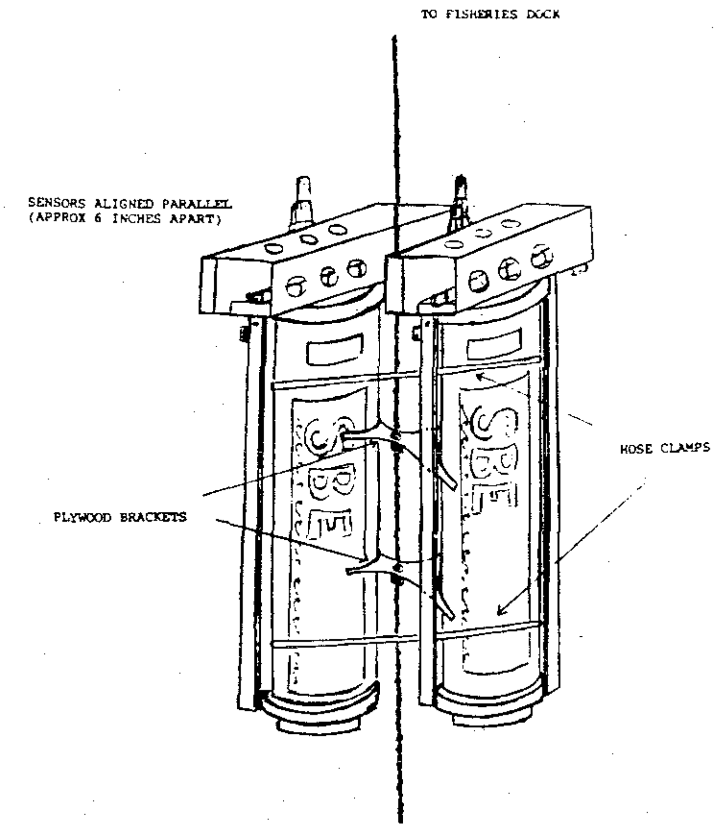

Figure 1. NMFS dock test deployment design whereby two *Seacats* were mounted side-by-side in order to compare data logged.

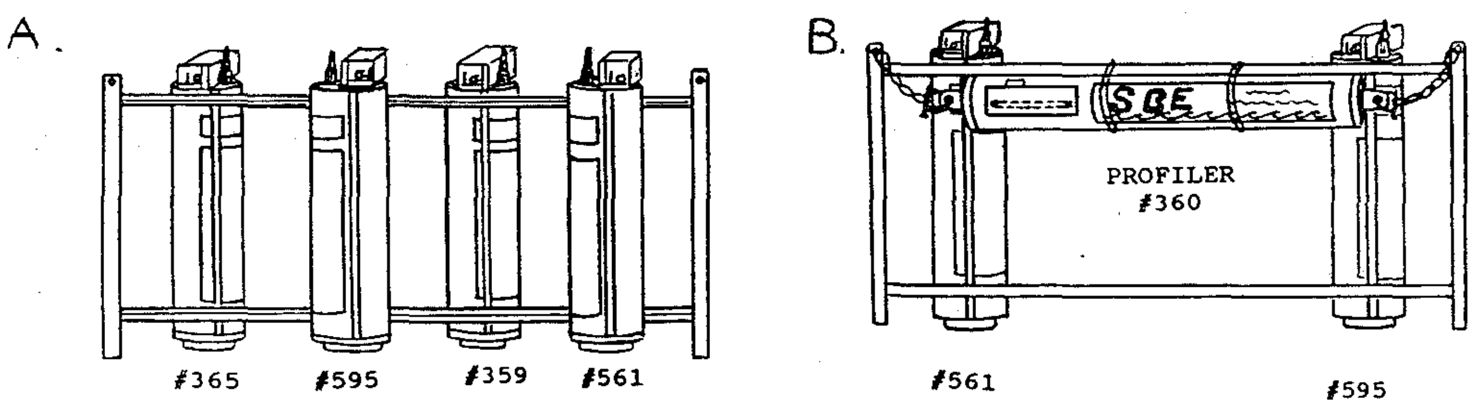

Figure 2. A) Testing frame on which the four *Seacats* were mounted and hung below the NMFS Dock. B) Test #5 set-up, in which the *Profiler* was braced between *Seacat* #561 and #595. Note that the *Profiler's* sensors are closest to those of *Seacat* #561.

were recovered and their data retrieved for examination.

TEST 2

Seacats #365 and #561 were deployed off the NMFS dock overnight (16 hrs) in the same manner described earlier. *Seacat* #561 replaced #359 in the testing program due to the failure of #359 during the first vertical test deployment. After #365 and #561 were recovered and their data retrieved, they were deployed vertically at 2.5 and 11 m respectively in another attempt to obtain a data set fulfilling the secondary objective of the testing program. The two were left to record for 14 days at a rate of one scan every 5 min. Due to strong tidal mixing in the area, no stratification was observed in the water column.

Although the objectives of the two vertical tests were not met, it should be noted that when the instruments were recovered there was a visible layer of "growth" on both instruments. The conductivity cells of the *Seacats* were coated with a thin layer of fouling matter.

TEST 3

After being rinsed with fresh water, *Seacats* #365 and #561 were once again deployed side-by-side off the NMFS dock. This test allowed for data comparison between two *Seacats* that had both experienced such fouling. They recorded data at a sampling rate of 1 scan every 5 min, from 11 September to 24 September, 1990. The purpose was to be able to make scan-to-scan data comparisons between the two Seacats that had been used in the testing program for nearly one month and hadexperienced visible fouling during the vertical deployments.

Part of the emphasis of the testing program was shifted to investigate the extent to which fouling would effect data quality. A set of SBE 4-05 antifoulant caps designed to fit onto the conductivity cell ends was purchased to reduce the effects of biological fouling. The end caps are impregnated with tributyl-tin oxide (TBTO), such that the water flowing through the cell is treated with the anti-foulant compound. Depending on the current strength and the biological activity of the water, the caps should last for 6 to 12 months in the field.

All subsequent test deployments were carried out with the recorders mounted side-by-side. After each recovery, the instruments were rinsed with fresh water and the conductivity cells were filled with distilled water for storage.

TEST 4

Seacats #365,#595,#359,and #561 were mounted on alternating sides of a testing frame with their sensor units parallel (Figure 2a). They began logging 1 scan every 5 min on 7 December, 1990 but were not deployed until 10 December. Just before the frame was hung off the NMFS dock, the conductivity cell ends of each *Seacat* were fitted with the anti-foulant caps. The testing frame was taken out of the water on 2 January, 1991. Quality control results from the reference water samples that were taken during Test 4 (one sample taken each week day) showed larger salinity offsets than had been expected. Two additional tests were carried out to investigate possible reasons for the unexpected offsets.

TEST 5

A short overnight test was conducted with SBE model 19 *Profiler* braced between *Seacat* #561, which had been used since the early test deployments in July, and *Seacat* #595, which had been used only once before (Figure 2b). The *Profiler* is designed to take vertical water profiles at sea and has been used for more than a year with impressive quality control results (+/-a few hundredths psu). The purpose was to observe the recording of the two *Seacats* relative to the *Profiler*. The scanning rate of the *Profiler* was reduced to one scan-per-minute to be sampling in sync with the two *Seacats*. The instruments were not fitted with the anti-foulant caps during this test.

TEST 6

The last test deployment was designed to investigate any possible consequences of using the anti-foulant caps that may have had a role in causing the high salinity offsets observed during Test 4. The *Seacats* were once again mounted on the testing frame from left to right in the following order: #595, #359, #561, #365. Only #561 and #365 were fitted with the caps. The frame was hung off the

NMFS dock on 14 February, 1991 and was recovered on 28 February, 1991. The data records ofthe two *Seacats* that were fitted with the anti-foulant caps were compared with those that did not have them fitted on the conductivity cell ends.

RESULTS

Throughout the series of tests conducted during the past year, very few operational problems were encountered with the *Seacats*. They began logging data at the requested time, date and sampling rate. There was no apparent "drift" in their timing precision. Only once did an instrument (#359) fail to perform during a test. This "technical" problem did not seem to be serious since it was returned from SBE within two weeks and has not experienced any operating difficulties since. The software provided by SBE makes communication with the instruments for initial set up (*i.e.* sampling rate and start time) and data retrieval very easy. The location of the 4 pin I/O cable connector is convenient in that the *Seacat's* housing does not have to be opened in order to retrieve data. Also, the placement of the battery compartment at the base of the housing is helpful to the user because it is separate from the electronics and allows for a quick and easy change of batteries.

The instrument's light-weight design was especially appreciated during this testing program. The *Seacats* were hand-carried and deployed off the NMFS dock for each side-by-side test. There was no need for a mechanical boom or winch that would be required for heavier, more cumbersome instruments. The aluminum bars that run alongside the housing allow the *Seacat* to be attached to a mooring cable, but a method of attachment is not provided. One disadvantage to using the *Seacat* is that there is no "real time" capability that would give the user the assurance that the instrument was operating properly, although this testing program showed it to be quite reliable.

Figures 3a and 3b show the temperature and salinity results from Test 1. The temperature records show no significant recording difference between the two instruments. It is suspected that the two warm peaks observed during the 46 hr series are a result of the influence of the tidal cycle combined with heat input from daily solar insolation. Flood tide occurred at 7:08 pm on 18 July, 1990 (hour 8 of the test). The salinity records show a distinct separation during the first 14 hr of the test that gradually became smaller. The recording level of #359 aligned with that of #365 by hour 16. A possible reason for the lag in salinity recording by #359 is that its conductivity cell was dry prior to the instrument's deployment. The platinized electrode surface of the cell must be fully saturated to ensure sensor accuracy. The salinity discrepancy during the first 14 hr of the test could reflect the time it took for the cell's surface to become fully immersed and saturated. However, the salinity records remain a few hundredths psu apart throughout the remainder of the test. The salinity quality control results (Figure 4) showed a general increase in offset (the *Autosal* value of the water sample being of higher salinity than both *Seacats*) up through sample #6 and then a sharp decline at sample #7. The first sample comparison was not included due to the 14 hr lag in #359's salinity record.

In Test 2 *Seacat* #561 replaced #359 due to the failure of #359 during the first vertical test. The 16 hr test showed no discernable difference in temperature recording. Figure 5 shows that there was a consistent salinity recording difference of approximately 0.08 psu. The newer instrument (#561) recorded higher salinity values than #365, which had previously been used in Test 1 and the first vertical test attempt. This is most likely because the conductivity cell of #561 had not been exposed previously to the testing field and was therefore cleaner than that of #365. The small scale fluctuations (± a few hundredths psu) in

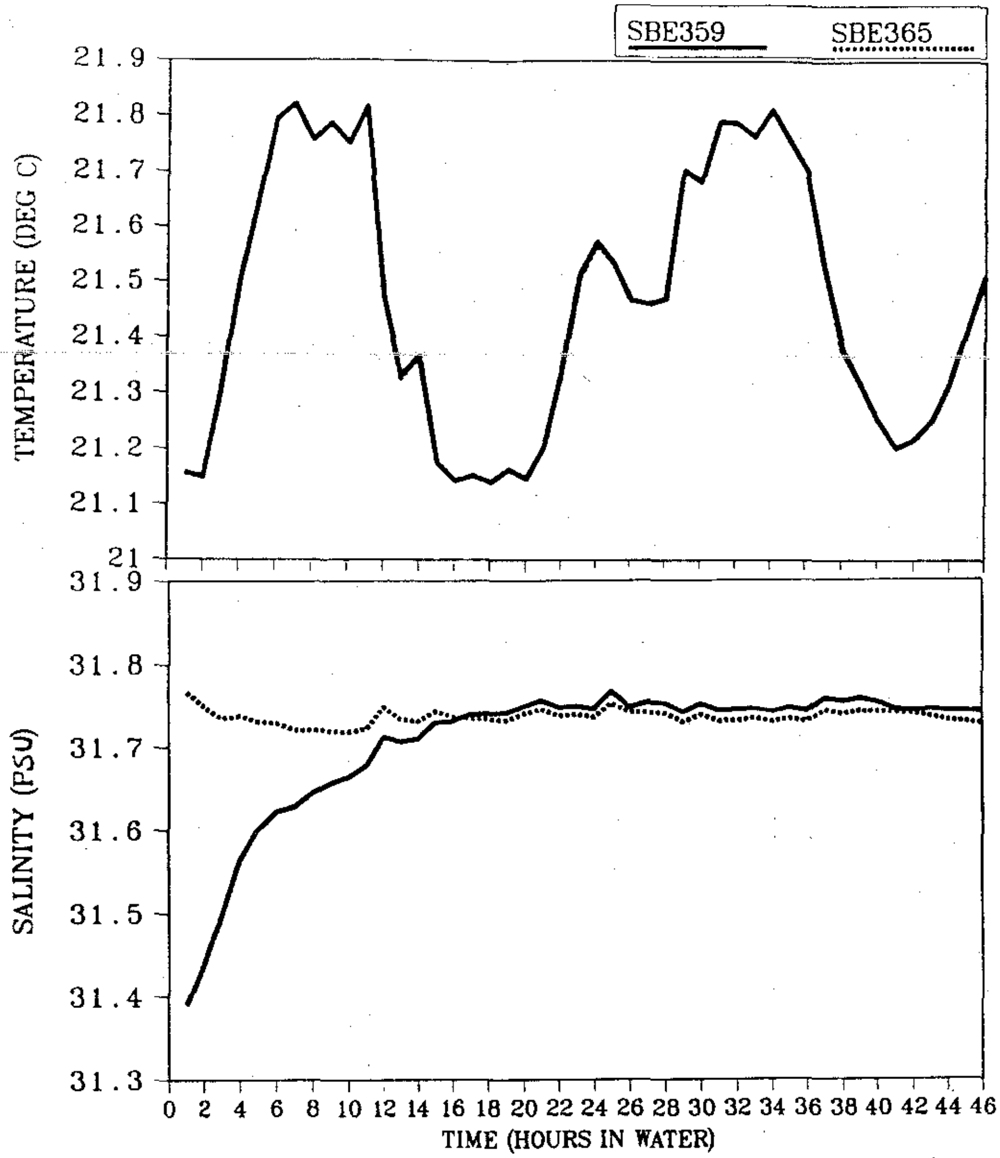

Figure 3. Temperature (a) and salinity (b) data from side-by-side Test 1.

the salinity data time series demonstrate the fine resolution and sensitivity with which the *Seacats* are able to log data. Only one quality control sample was taken during Test 2 and it was taken shortly after the *Seacats* were deployed. *Seacat* #561 recorded 0.0260 psu lower than the *Autosal* sample value while *Seacat* #365 recorded 0.1056 psu lower than the *Autosal* reference value.

The conductivity cells of #365 and #561 were visibly fouled when the two were recovered from side-by-side Test 3. Despite this layer of growth within the sensor unit, there were no discrepancies observed in the *Seacat* temperature records when the two were compared. Random "spikes" in the salinity data showed up as very prominent drops in salinity (Figure 6). It is believed that this was caused by something floating or swimming (*i.e.* zooplankton) through the conductivity cell. The drop in salinity that shows up in both *Seacat* records on the third day of Test 3 is not due to random fouling but is a result of rain that fell the afternoon of 14 September.

The salinity record fluctuations parallel each other, although #561 recorded nearly 0.07 psu lower than #365. An unexplained "flip" in recording level shows up during day

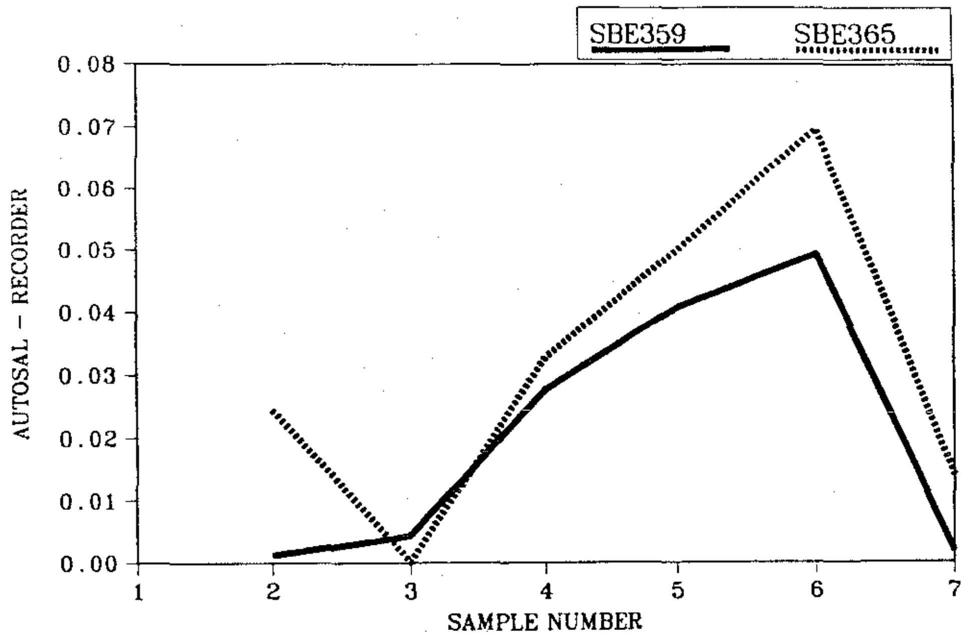

Figure 4. Salinity quality control results from side-by-side Test 1. The difference of the water sample salinity and that of each instrument was plotted against sample number.

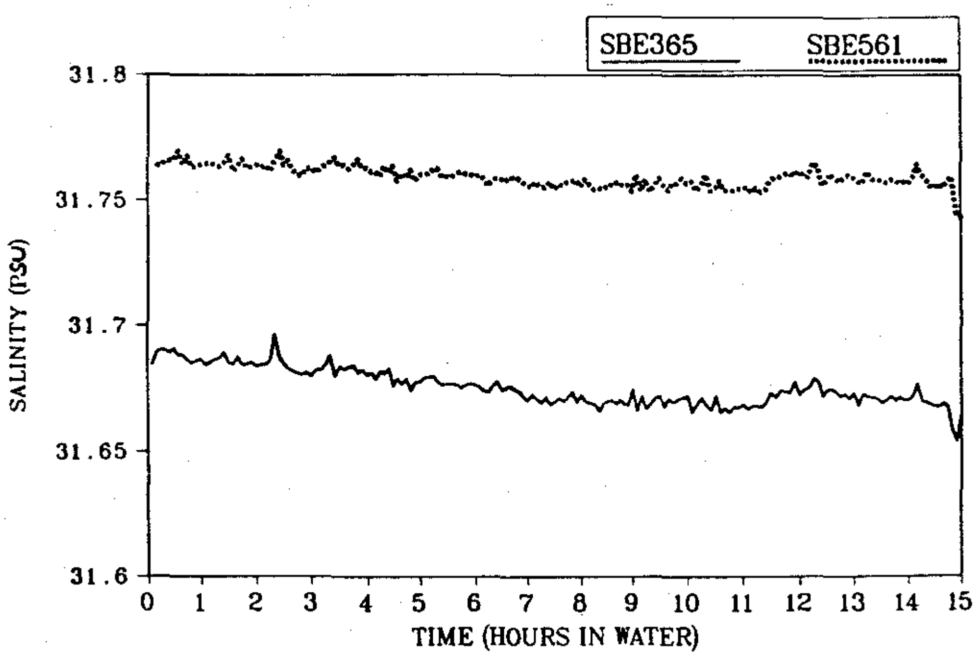

Figure 5. Salinity data from side-by-side Test 2, showing the progressive fouling of #365. Number 561 was being used for the first time and recorded higher salinity values than #365.

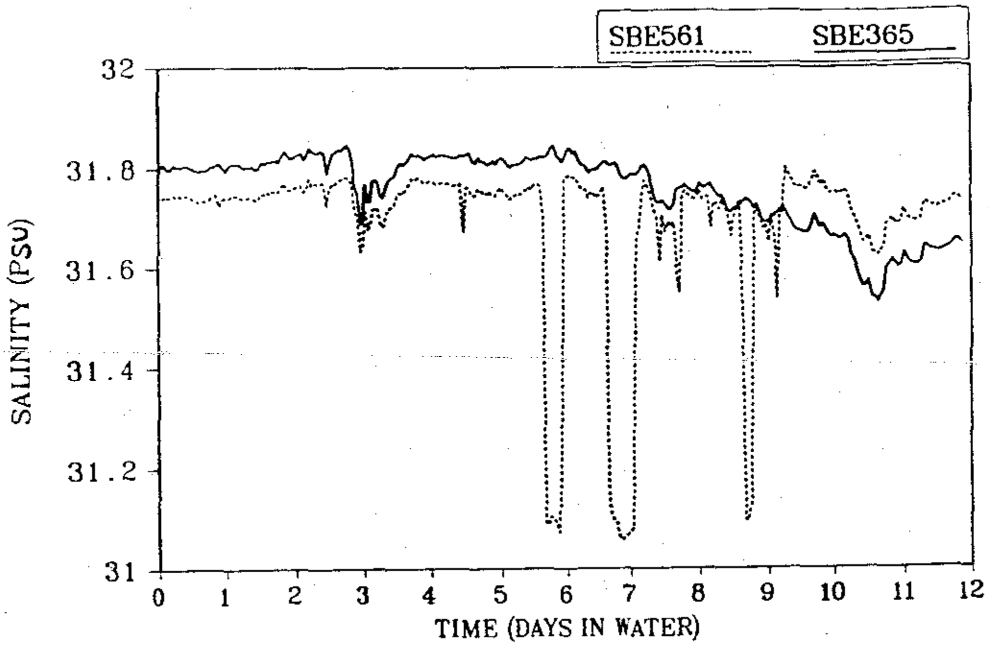

Figure 6. Salinity data from Test 3 showing random fouling "spikes." The drop in salinity beginning just before day 3 (Sept. 14) is due to rainfall and not fouling.

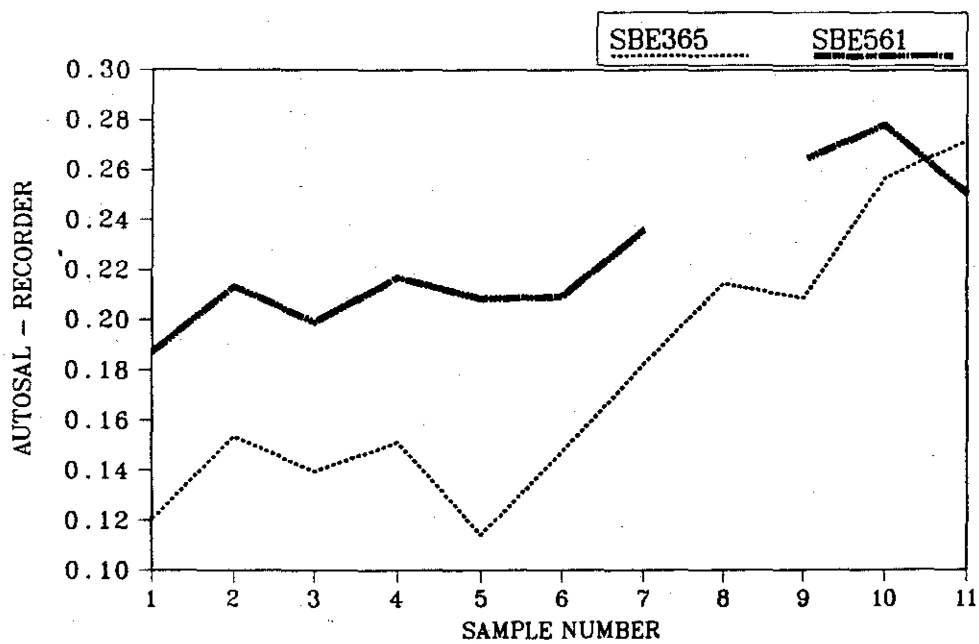

Figure 7. Salinity quality control results from side-by-side Test 3.

#9 whereby *Seacat* #561 records approximately 0.08 psu **higher** than #365 although the fluctuations still parallel each other. The salinity quality control results showed relatively high offsets (> 0.10 psu) between the *Autosal* readings and that of both *Seacats* (Figure 7).

The offsets increased progressively with time. *Seacat* #365 shows a lower offset than #561 until sample #11 which reflects the flip in the recording level that occurred on day #9. No offset value is given for *Seacat* #561 for sample #8 because it coincides with one of the fouling

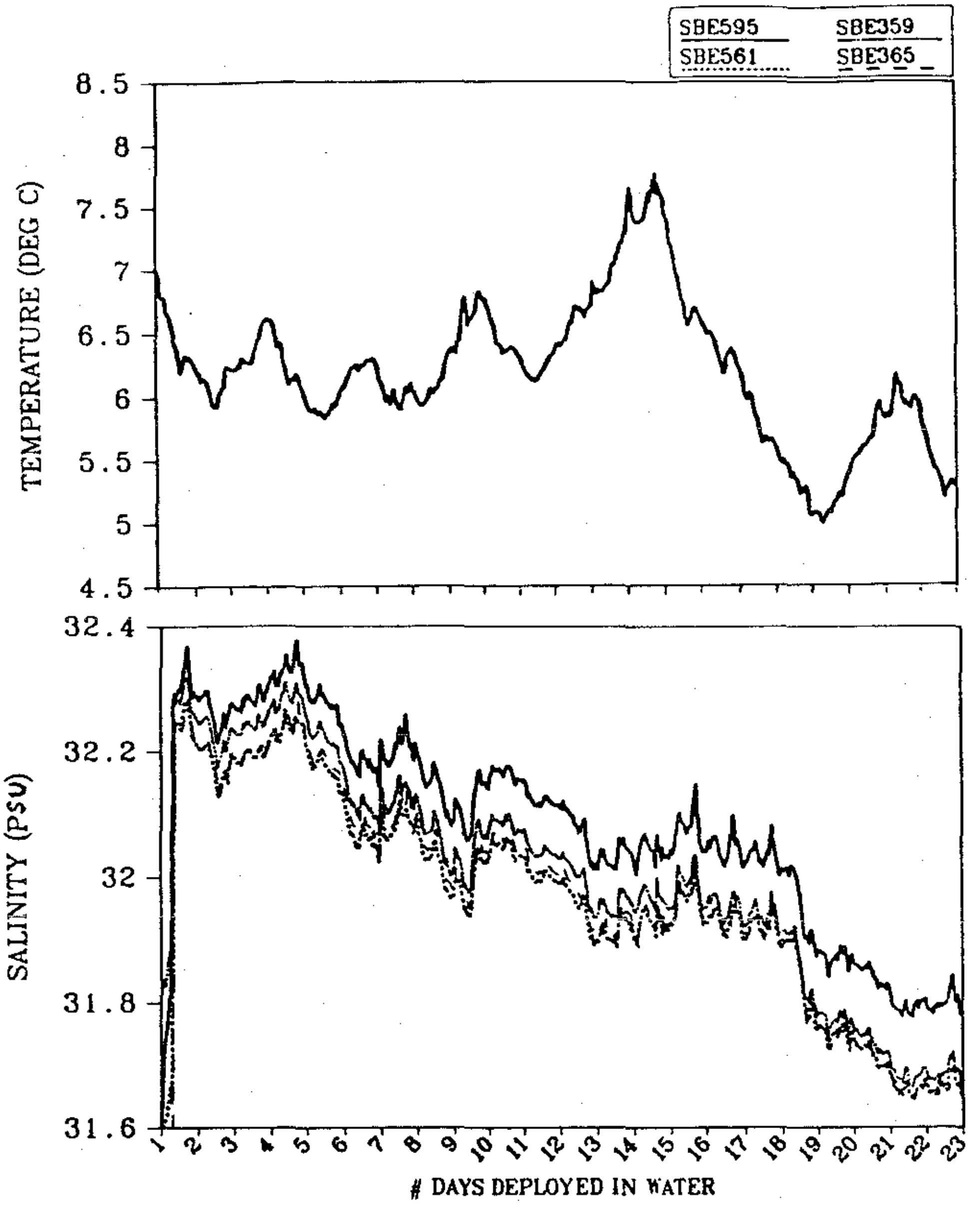

Figure 8. Temperature and salinity data from Test 4. The prominent temperature peak beginning on day 11 was a result of three days of unusually mild weather in December that were followed by a few days of rainy and windy conditions. The discrepancy in the salinity records reflect the condition of each instrument's conductivity cell.

spikes in the salinity data.

Side-by-side Test 4 was the first time in which all four *Seacats* were deployed together. There was no visible growth seen on the instruments or in the conductivity cells when the testing frame was taken out of the water. However, Test 4 took place in December, a time of year when one would expect the testing waters to be relatively free of fouling activity. Figure 8 shows the temperature and salinity records from side-by-side Test 4. Once again, there were no significant discrepancies observed in the temperature records throughout the time series. The gaps between the salinity data records appear to be related to how often the instrument had been used, which in this testing program is comparable to the extent of the conductivity cell's contamination. Any coating on the conductivity cell remaining from previous tests was reflected in subsequent tests by lower values of salinity recording. *Seacat* #595 recorded the

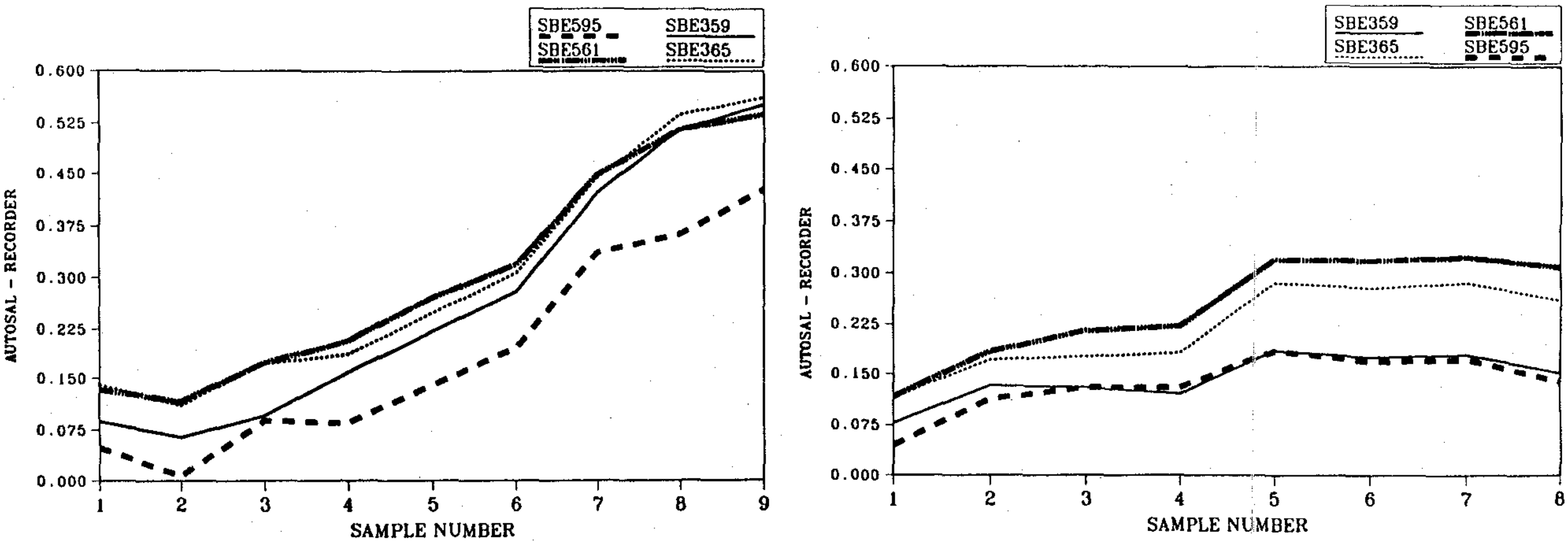

Figure 9a,b. Salinity control results from Test 4 are shown at left, quality control results from Test 6 at right. In Test 4, the water samples were consistently of higher salinity than each *Seacat* record. *Seacat* #595 showed the lowest level of offset because it was in use for the first time. In Test 6, the plot shows a similar trend of increasing offset with time that was observed in Test 4. The differences did not progress from where they left off in the other test, but showed a similar starting point.

NOTE: The sample numbers in these plots do not correspond to the same amount of in-water time. Test 4 was 21 days long while Test 6 lasted only 14 days.

highest salinity values and was being used for the first time. *Seacat* #359 recorded salinity values intermediate between the highest and the lowest records and was being used for its third time. The bottom two records are those of #365 and #561 which were both being tested for the fifth time. The oscillations in the time series are the same for all four records, differing only in the salinity level at which they record. Lower salinity values were observed in the beginning of the time series. Once again it is believed that this was due to the conductivity cells sitting dry for two days prior to the testing frame being put in the water. When the *Seacats* were put in the water, there could have been a delay before the insides of the conductivity cells were once again fully saturated.

Salinity quality control results from Test 4 showed a linear progression of greater recording offset with time (Figure 9a). The water samples were consistently of higher salinity than the *Seacat* records. The offsets were higher than what had been anticipated because when the testing frame was taken out of the water there was no growth visible in the cells as opposed to what was observed during the summer tests. The "newest" *Seacat*, #595, had the lowest level of increasing offset and the two instruments that had been used most, #365 and #561, showed the highest. Because of the surprisingly large salinity offsets from this test, the reference water samples were reanalyzed on a second *Autosal Salinometer* and similar results were obtained.

Salinity quality control results from Test 5, the short overnight test with the SBE *Profiler*, were notably improved from those of Test 4. The two *Seacats* in Test 5 were **not** fitted with the anti-foulant caps. The offsets did not proceed from where they left off in Test 4. Instead, the results were similar to the first sample comparisons shown in Figure 9a. At first this finding caused some suspicion about what the anti-foulant caps might be doing to the inside of the conductivity cells. Temperature and salinity data from Test 5 are shown in Figure 10. A gradual lag in *Profiler* recording was observed but was most likely because the *Profiler* does not have the same timing precision as the *Seacats*. The salinity data show that *Seacat* #595 recorded similarly to the *Profiler* (although the *Profiler's* sensors were closest to those of #561) and that #561 logged salinity values approximately 0.1 psu lower than the other two instruments. This was not too surprising since it was expected that the newer instrument would record closely to the "trusted" *Profiler* and that the *Seacat* used most in the testing program would record lower salinity values due to existing contaminants in the conductivity cell.

The water sample results from Test 6 (Figure 9b), in which only *Seacats* #365 and #561 were fitted with the anti-foulant caps, showed a similar trend of increasing offset with time that was observed during Test 4 (Figure 9a). Once again, the offsets started off relatively small and then gradually increased, although they did not progress as high as the last samples in Test 4. However, Test 4 was seven days longer than Test 6. Sample #8 in Test 6 does not correspond to the same amount of"in water time" as sample #9 in Test 4. It is uncertain whether or not the offsets would increase to the same level they did in Test 4 if the four *Seacats* had been left in the water for another week.

The salinity records from Test 6 show a distinct separationbetween the two instruments with anti-foulant caps from the two without them (Figure 11). *Seacats* #365 and #561 showed the highest level of salinity offset in this test (and the lowest level of recording in the time series). This is not necessarily caused by the anti-foulant caps but is most likely because these instruments had been used during the previous summer. The caps could prevent further fouling but any existing contamination would persist which could cause the observed differences in their level of recording.

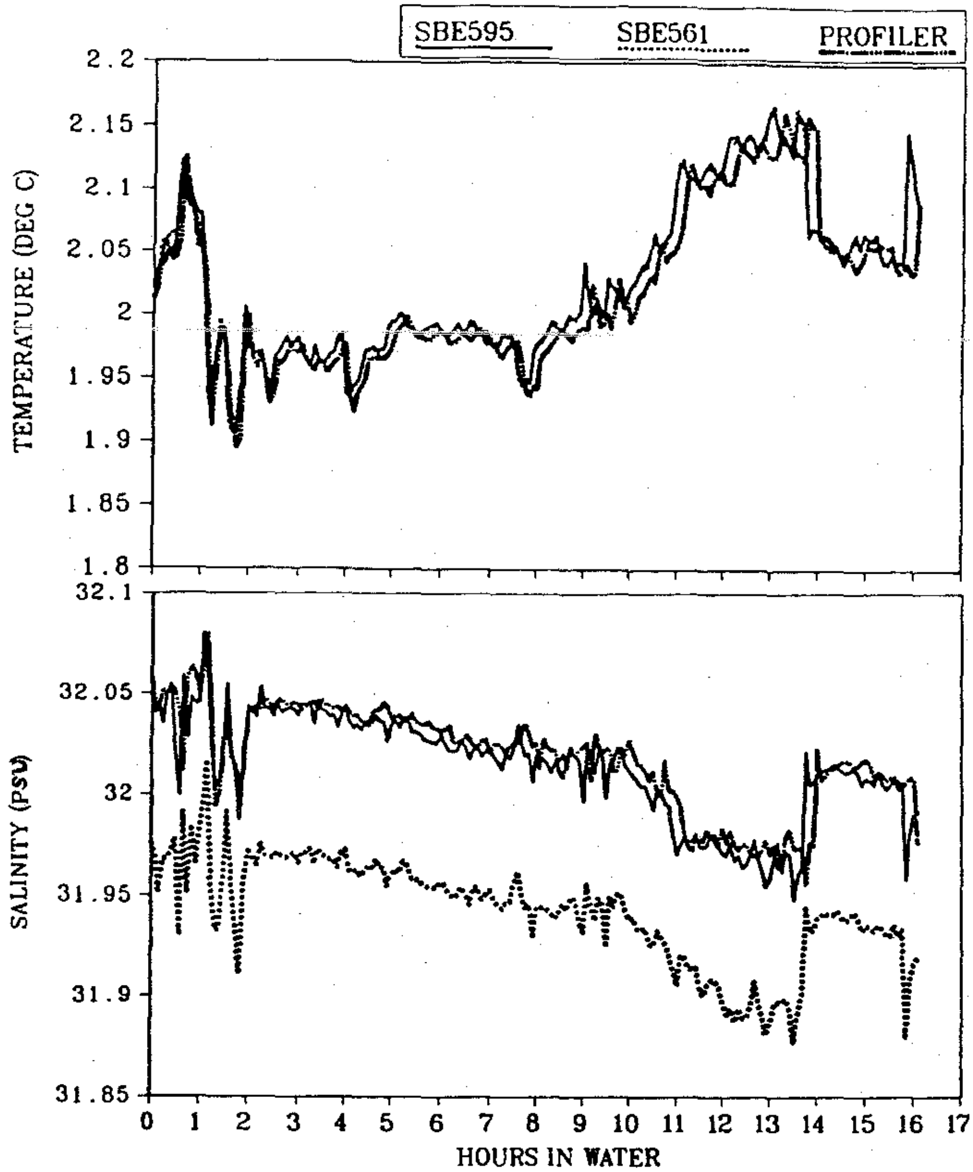

Figure 10. Temperature and salinity data from overnight Test 5 with *Profiler*. The *Profiler* does not have the same timing precision as the *Seacats*, which caused the lag in its recording of both the temperature and salinity data shown in the figure.

DISCUSSION

Early in the testing program it became evident that the quality of salinity data obtained from the recorders was related to the condition of the conductivity cells. According to SBE, the principal determinant of conductivity, and therfore salinity, data quality is the condition of the platinized electrode surface of the cell, which can be degraded by exposure to biological or chemical contaminants. The more an instrument is used, the greater the risk that the conductivity cell might be exposed to chemical or biological "contaminants." *Seacats* #359,#365 and #561 experienced considerable fouling during the two vertical test deployments, and this was reflected in the salinity data from all their subsequent uses. Although there was no quality control reference, the fouling of the instrument's sensors did not appear to have an effect on temperature data. There were no significant discrepancies observed in the tem-

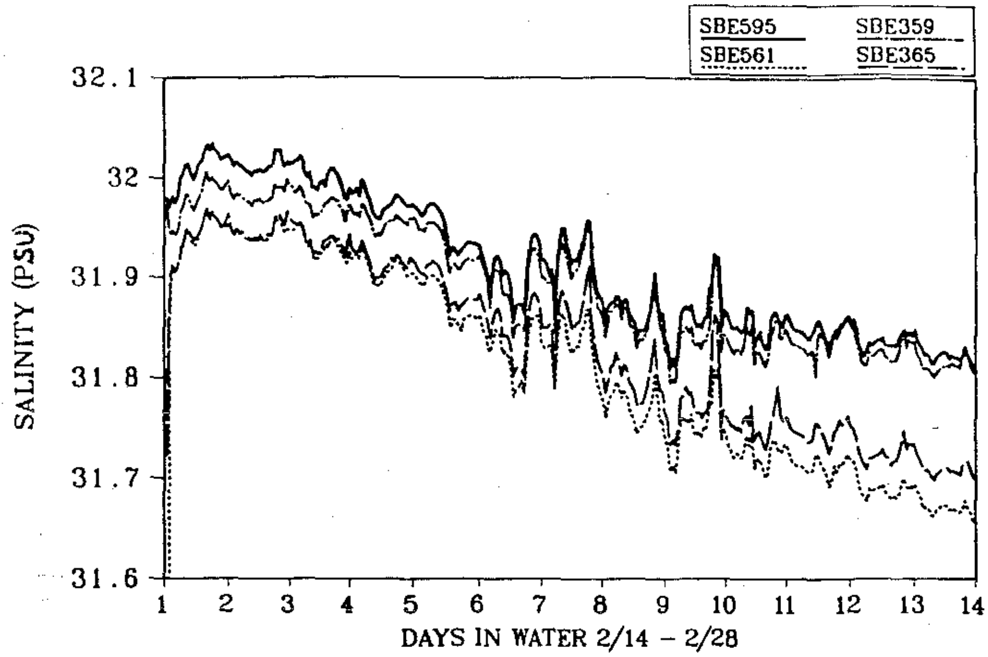

Figure 11. Salinity data from Test 6 in which only *Seacats* #365 and #561 were fitted with the anti-foulant caps. The two instruments with the caps recorded at a lower level but this may be due to existing impurities in their cells.

perature data records throughout the entire series of tests. Evidence of the warming and cooling of the surface waters due to solar insolation, nightime cooling and local storms was observed.

The random fouling of the conductivity cell that appeared in the salinity data records as very prominent downward "spikes" (Figure 6) is of less concern than its progressive degredation. The fouling spikes readily stand out as anomalous values relative to the entire time series (a drop in salinity greater than .5 psu in less than 14 hr) and are easily edited from the data set. The tidal cycle provides regular "flushing" of the conductivity cell. If the tidal flow is strong enough, any particles stuck in the cell that can cause the random "spikes" in the salinity records, might be removed. However, this does not mean that they will not be replaced by particles flowing within the water of following tides.

The progressive fouling of the conductivity cell that was shown to occur with increased time in the water as well as increased total use warrants attention. The salinity quality control results showed not only that the individual offsets increased with time but also that the mean salinity offsets increased with continued use of the instrument. The latter is probably because the conductivity cells were not cleaned, other than being rinsed with fresh water in between each use. Residual contamination in the conductivity cells would cause lower salinity values when the instruments were used next. The environment in which the *Seacats* were being tested is an important consideration to the overall findings of the testing program. The "testing" dock is in an area of high productivity and variablility, and is susceptible to fouling organisms and contaminating chemicals.

In comparing the quality control results throughout the testing series, the first samples, usually taken after the frame had been in the water for a day, had the best results (*i.e.* smallest difference between the salinity value of the water sample and that of each corresponding *Seacat* value). The results gradually worsened with each subsequent sample taken throughout the deployment. The "improved" quality control results from the overnight test with the profiler (Test 5) can therefore be misleading. This test lasted only 15 hr and it cannot be claimed, with any certainty, that the offsets would remain small if the test had been continued. It seems likely that the progressive quality control offsets of Test 4 and 6 were caused by some characteristic(s) of the testing site rather than by the anti-foulant caps or the *Seacats*. The fact that the cells "looked" clean after these tests was not proof that they had not been contaminated. It is now believed that the cells have been chemically contaminated by an oil or grease coating from the testing dock pilings or resulting from near shore boating activity. This type of coating would not be removed necessarily with a fresh water rinse but would require an appropriate detergent.

Despite the "harshness" of the testing site, the *Seacats'* response to small scale salinity fluctuations does not seem to be impaired by progressive fouling. For example, the oscillations in the salinity records shown in Figure 11 were generally the same for all four *Seacats*, differing only in the salinity level at which they record. The high degree of variablilty of the testing site is not characteristic of the offshore waters where it is anticipated that the *Seacats* will be deployed. A linear salinity correction will need to be applied based on quality control sampling. When the *Seacats* are moored offshore, the sampling would entail CTD profiles next to where they are deployed.

CONCLUSION

The testing of these instruments that has been conducted thus far has provided valuable information for their future use offshore. A great deal of experience has been gained in terms of their operation and capabilities. The preliminary results that have been presented in this text must be weighed in terms of the questionable environment in which they have been recording. An ideal testing site would have the *Seacats* moored in deeper, less variable water where the influence of near shore activites (*i.e.* road run-off, boat traffic, oil) would be reduced. Also, the conductivity cells of each instrument will be cleaned properly before any further deployments are made. In this way there would be no residual contamination from previous tests that might complicate the data analysis.

The *Seacats* showed high sensitivity in data acquisition. The influence of tides, storms, precipitation, and solar insolation was reflected in the data records throughout the testing program. A method of mooring attachment is not provided by SBE and one will have to be designed for their use on a mooring cable. The fouling of the conductivity cell remains an important consideration for future deployments. Anti-foulant caps should be used to prevent growth in the cells that can cause low salinity recording. It is hoped that the offshore waters do not contain the amount of biological and chemical contaminants of this testing site.