Stability of Water Temperature in the Conductivity and Temperature Calibration System and Results of Calibration Experiments

Asako INOUE[1], Motoki MIYAZAKI[2], Kenji IZAWA[3]
Kentaro ANDO[3], Yasushi Takatsuki[3], Keisuke MIZUNO[3]

1:Department of Marine Science, Marine Works Japan LTD
2:Climate Variations Observational Research Program, Frontier Observational Research System for Global Change
3:Ocean Observation and Research Department, Japan Marine Science and Technology Center

Abstract: The purpose of this study is to investigate the temperature distribution in the bath of the conductivity and temperature calibration system (CT bath system) equipped for Japanese-Argo program in 2000, and to show the results of calibration of sensors which were actually launched in 2001 in the North Pacific as the Japanese-Argo floats.On the temperature and conductivity sensor calibration, controlling temperature of water in the bath during calibration is the most important issue, so the temperature distribution during calibration was examined. As the results of these experiments, water temperature was well controlled within 1.7mK.

The calibrations before the deployment of floats were also performed for eight sensors. The results of JAMSTEC calibration showed that the difference of temperature calibration from the manufacturer's calibration was within 1mK with the standard deviation of less than 0.5mK, and that of conductivity calibration from the manufacturer's was 0.5mS/m (corresponding to 0.0042psu at 24 degree-C) with the standard deviation of 0.2mS/m (corresponding to 0.0016psu at 24 degree-C).

Keywords: Argo project, Argo profiling float, Calibration bath system, temperature distribution, error range

1. Introduction

The "Argo project," an international project launched in 2000, is a large-scale project that will attempt to make real-time measurements of variations in the ocean on a global scale. In Japan, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Land, Infrastructure and Transport are collaborating to promote this project, "the construction of the Advanced Ocean Monitoring System (Argo project)," as part of the millennium project launched in FY 2000 with the cooperation of the Fisheries Agency. In this project, nearly 3,000 middle-layer floats (hereinafter referred to as "floats") will be deployed in oceans worldwide to obtain vertical profiles of the water temperature and salinity from the sea surface down to depths of 2,000 m. The data will be collected in real time, and will be used to dramatically improve long-term predictions of climate variations (Mizuno, 2000 [1)]). Once deployed, these floats will drift at a depth of 2,000 m, and will resurface every 10 days to transmit the temperature and salinity data collected during its ascent. After the data is transmitted, the float will once again dive to a depth of 2,000 m. The battery life of the floats is approximately 4 years, and the cycle of ascent and descent will be repeated throughout this period. The floats will be operated without maintenance work during this time, so it is essential that their mechanisms be durable and that there sensors feature high temporal stability.

A study is currently underway at the Japan Marine Science and Technology Center (JAMSTEC) to improve the precision of the onboard sensors of the floats for the Argo project. The present goal is to achieve precision of 0.01 psu for the salinity sensors and 0.005°C for the temperature sensors, a level of precision that represents a great technical challenge. Salinity is calculated from three elements of the seawater – conductivity, temperature, and pressure – so highly precise measurements of conductivity and temperature are required to improve the precision of the salinity sensors. It is highly likely this precision could be achieved if the float sensors could be maintained and managed with instruments such as the Autosal® laboratory salinometer used on land or the CTD (conductivity, temperature, and depth) sensors used on vessels.

However, it is extremely difficult to retrieve floats to perform maintenance and management work once they have been deployed at sea.

Riser and Swift (2001)[2] have surveyed the temporal shifts in the sensitivity of conductivity sensors onboard deployed floats. The sensors used in their study were SeaBird SBE41-type sensors, which are electrode-type conductivity sensors of the same type used at JAMSTEC in FY 2000. Several floats measured lower salinity values for several cycles immediately after they were deployed, but the sensitivity of their sensors gradually returned to normal. However, most float sensors are extremely stable even three years after deployment, and have provenable to maintain their high precision. It is believed that the low salinity values measured immediately after deployment are due to marine-growth inhibitors (ship-bottom paint) applied at the intake of the conductivity-sensor cell flowing into the interior walls of the cell. This results in a reduction in the size of the sensor surface, causing a decrease in the measured conductivity (lower salinity values). Riser and Swift (2001)[2] have reported that the sensors of the same type used in their study maintained precision of 0.01 psu in salinity for several years.

However, some sensors of the same type have clearly displayed temporal shifts in sensitivity. As the number of deployed floats increases in the future, the number of sensors requiring data calibration will increase as well. To prepare for this, a study is being conducted to develop a method for calibrating data based on climatological data (Kobayashi et al., 2001[3]). The calibrated value of the sensor prior to deployment is one of the most reliable measurements of data calibration. It is therefore important to conduct maintenance and management of sensor sensitivity using a calibration system before the floats are deployed.

2. Argo-Float Calibration Bath

At JAMSTEC, we have installed a large calibration bath manufactured by SeaBird Electronics, Inc., (Photo 1) in order to conduct independent maintenance and management of the float-borne sensors. This calibration bath is filled with artificial seawater maintained at a constant salinity; the temperature can be stabilized at several points between 1°C and 30°C, and instruments can be tested simultaneously for temperature and conductivity at approximately 3-6 S/m. A similar test method has already been adopted for the Triton buoy sensors (Matsumoto et al., 2001[4]).

The Triton buoy calibration bath uses the SeaBird SBE3-type temperature sensor and the SBE4-type conductivity sensor as references. In addition to these instruments, the Argo-float calibration bath is equipped with an SBE5 pump to

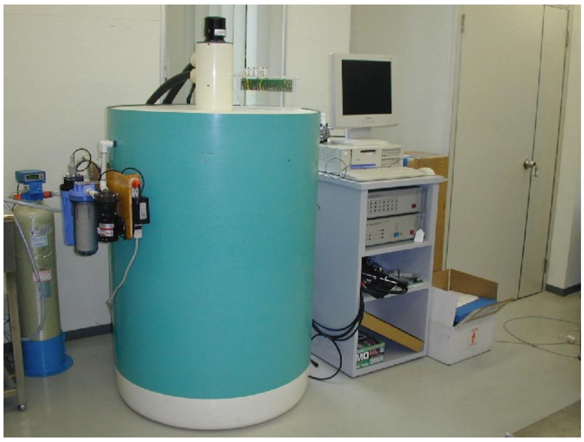

Photo1 Argo float calibration bath (left) and controller (right)

circulate water from the temperature sensor to the conductivity sensor. As a duct connects the two sensors, they will take measurements of the same mass of seawater. Since the circulating seawater will also be supplied to the water sampler, the sampled seawater will be the same as that used in the conductivity measurement.

The rack next to the calibration bath in Photo 1 holds, from the top, a PC unit, a sensor interface unit, and water-temperature controls. Although not shown in the photo, a large chiller for heating and cooling the seawater in the bath is also provided. The calibration bath can hold five float sensors at once for calibration and, since the Argo float sensors are larger than Triton buoy sensors, the Argo calibration bath is larger (ϕ 54 cm × 100 cm (H), 250 liters) than the Triton calibration bath (100 liters). In contrast to the Triton buoy, which features cooling coils on its bottom and heating coils in its mid-section, the Argo calibration bath features both types of coils in its midsection.

Figure 1 shows the structure of the Argo-float calibration bath and the convection of seawater inside the bath. Inside the cylinder placed in the center of the calibration bath are two stirrers and heating (top) and cooling (bottom) coils. The seawater flows downward inside the cylinder and upward outside the cylinder.

Photo 2 shows Argo float sensors detached from the float placed in the calibration vessels. When the float sensors are calibrated, the sensor is detached from the main body of the float, and the data-transmission antenna is removed so that the sensor will fit inside the bath. The sensor is then placed in the calibration vessel. The sensor is connected to the sensor interface unit via the underwater connector located at the bottom of the vessel. An isolation circuit including a power source is integrated into the sensor interface unit to prevent interference between the electrodes of the sensors. A/C converters and photocouplers isolate the power source and the serial signals,

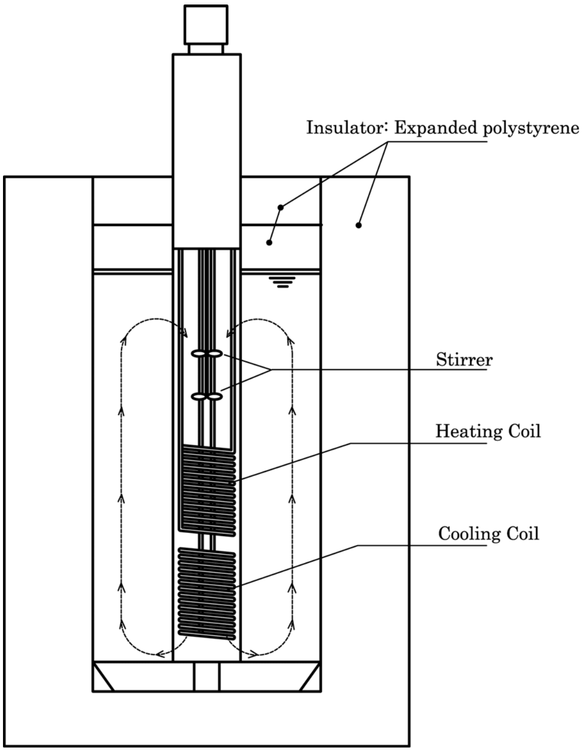

Fig.1 Configuration of Argo calibration bath

respectively. By contrast, in the Triton-buoy calibration bath, each of the sensors is powered by internal battery cells and, since communication with the sensors is conducted by electromagnetic-induction transmission, the sensors are already isolated, so there is no need to isolate them further as in the Argo calibration bath.

To precisely test the various electrode-type and inductive sensors developed for the floats using this calibration bath, the temperature characteristics of the bath must be confirmed and its performance assessed. In this paper, we will report on the results of experiments to evaluate the thermal distribution inside the calibration bath. We have also conducted tests on the SeaBird SBE41 sensors deployed at sea, and the EXCELL-type sensor manufactured by Falmouth Scientific, Inc., that was developed for the floats, and the results of these tests will also be reported.

3 Performance Assessment of the Calibration Bath

Experiments were conducted to evaluate the thermal distribution inside the bath. First, the instrument error of the temperature sensor of the same type was determined against the reference using a compact constant-temperature bath. Then, the temperature sensors were distributed inside the bath in the radial and vertical directions. In all cases, the reference was placed in its designated position on a hook inside the bath, and this was considered the reference point.

Photo2 Argo CT(Conductivity and Temperature) sensors(SBE41) attached to end-cap for connecting to signal cable. Before calibration, sensors have to removed from Argo float

3.1 Calibration of the Instrument Error Between Temperature Sensors

SeaBird SBE3-type temperature sensors were used in the tests. The precision and instrument error of the sensors were confirmed in a SeaBird compact constant-temperature bath (ϕ 35 cm × 54 cm (H), 55 liters). At the time of the experiment, the temperature control unit of the compact bath was not working, so the test was carried out only at room temperature and the water inside the bath was stirred and kept in equilibrium at room temperature. From the past history of inspections conducted by SeaBird Electronics, Inc., it is known that the instrument error in SBE3-type temperature sensors occurs due to a shift in the intercept and not from a change in the slant of the calibration curve (SeaBird Electronics, 1995[5)]), so the intercept was calibrated using measurements obtained at a single temperature point of room temperature. Measurements were taken in a cycle of 0.25 sec for 5 minutes. The sensor used as reference (Serial number (S/N) 2522) had the latest date of calibration by SeaBird at the time. The results are shown in Fig. 2. It can be seen that the temperatures measured by all sensors rose gradually throughout the experiment. This is due to the malfunctioning of the temperature controls discussed earlier, and indicates that the water temperature gradually rose to room temperature. However, the time-temperature curves are parallel during the experiment, indicating that, at any given time, the water temperature inside the constant-temperature bath is uniform. Table 1error for each sensor used in the temperature distribution experiment. The standard deviation of the instrument error for all sensors is less than 0.1 mK. Sensor S/N1207 arrived from SeaBird Electronics, Inc., after this instrument error test was conducted; however, since SeaBird had calibrated it just before shipping, it was not recalibrated at JAMSTEC. Due to the fact that sensor S/N1207

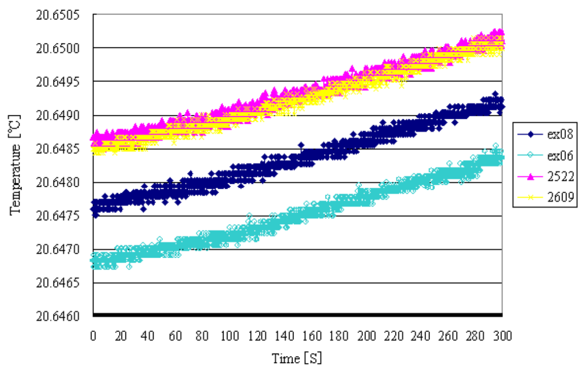

Fig.2 Time change of temperature measured by four SBE3 sensors during one-point calibration near room temperature. The water temperature in the bath gradually increased towards room temperature, however differences among each sensor were almost unchanged during calibration.

S/N	Date of Calibration at SeaBird	Average Difference[mK]	Standard Deviation [mK]
ex08	07-Jul-99	-0.9	0.086
ex06	30-Jul-99	-1.8	0.086
2609	15-Sep-00	-1.0	0.087
2522	22-Sep-00	—	—
1207	18-Nov-00	—	—

Table1 Serial Numbers off all sensors used for measurement of temperature distribution, and the average and standard deviation of each sensor referred from S/N2522. The date of calibration by manufacture is also shown.

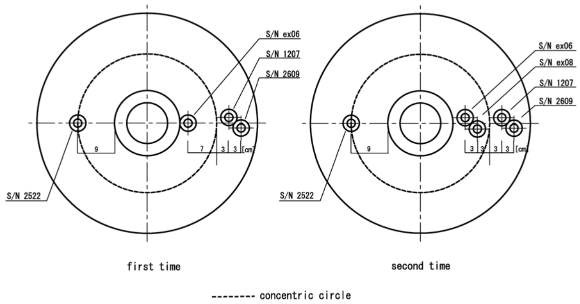

Fig.3 Locations of temperature sensors (SBE3) during the measurement experiment of temperature distribution in radius direction.

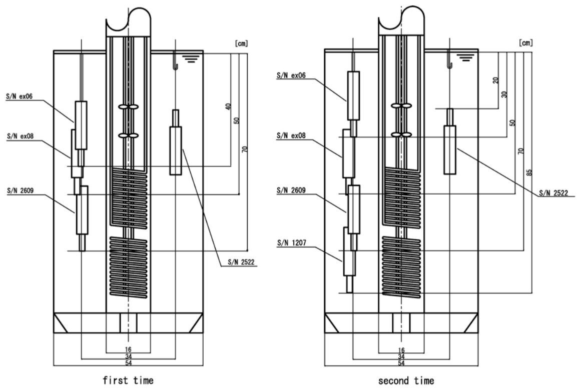

Fig.4 Locations of temperature sensors (SBE3) during the experiment of temperature distribution measurement in vertical direction,

had not been calibrated with the other sensors, during the temperature-distribution measurement experiment it was placed in a position at which the precision was expected to be the worst, and the results were used only for reference purposes.

3.2 Positions of the Temperature Sensors and Measurement Method

From previous measurements using SeaBird SBE41-type sensors, it was known that the temperature inside the bath displays a concentric distribution. Six hooks for the sensors are provided in the calibration bath, with each hook in a symmetrical location. The positions of the sensors were changed three times relative to the reference sensor (fixed position), and measurements were taken from 1°C to 30°C. In all positions, the difference from the reference point was less than 2 mK, and the calibration bath was confirmed to feature the water-temperature precision required by the Argo project. Therefore, in the present temperature-distribution measurement experiment, measurements were taken in the radial and vertical directions, twice for each direction. Sensor S/N2522 was used as a reference. The temperature was set in 7 steps at 30°C, 24°C, 20°C, 15°C, 9°C, 5°C, and 1°C. In the early stages of the experiment, the chiller was not providing proper temperature control and stable low-temperature conditions could not be obtained, so data for only four temperature points, 30°C, 24°C, 20°C, and 15°C, are available for the 1st round of measurement in the radial direction. Measurements were begun at each step after the standard deviation at the temperature for the reference sensor became less than 3 mK, and the temperature had been maintained for 1 hour. The measurements taken at each temperature lasted approximately 10 minutes. Figure 3 shows the sensor positions inside the bath during the 1st and 2nd measurements of temperature distribution in the radial direction, and Fig. 4 shows the sensor positions for the 1st and 2nd measurements taken in the vertical direction. In all measurements, the reference sensors were positioned 20 cm below the surface, where the sensor hook is located, and 9 cm from the stirrer, with the sensor facing up. In the 1st round of measurements in the radial direction, sensor S/Nex06 was placed 7 cm inward from the point symmetrical to the reference sensor on the concentric circle containing the reference sensor (the reference circle). S/N2609 and S/N1207 were placed 3 cm and 6 cm away from the symmetrical point of the reference circle. In the 2nd round of measurements in the radial direction, S/Nex08 and S/Nex06 were placed 3 cm and 6 cm inside the reference circle, and S/N2609 and S/N1207 were placed 3 cm and 6 cm outside the reference circle. The sensors were placed 20 cm below the surface, facing up. In the 1st round of measurements in the vertical direction, the sensors were placed facing down on the reference circle at depths of 40 cm, 50 cm, and 70 cm. In the 2nd round in the vertical direction, the sensors were placed facing down at 30 cm, 50 cm, and 70 cm below the surface.

3.3 Results of the Temperature-Distribution Measurements

Table 2 shows the temperatures measured by the reference sensor and the standard deviations at each temperature. It can be seen that the temperature in the calibration bath during the experiment was stable, with standard deviations between 0.2 mK and 0.7 mK.

Figure 5 shows the results of temperature-distribution measurements in the radial and vertical directions. All sensors were pre-calibrated according to the instrument error determined in the earlier section. The difference measured at each temperature by the reference sensor in the 1st and 2nd rounds were corrected by adjusting all measurements based on those obtained in the 2nd round, and adding the difference to the 1st measurements. It can be seen from Fig. 5 that, in the measurements taken in the radial direction, the average difference in water temperature from the reference at a depth of 20 cm within a ring extending 7 cm inside the reference circle and 3 cm outside, is less than ±2 mK. In the vertical direction, the average difference from a depth of 20 cm to 70 cm is less than ±1 mK.

Set Temperature	Measurements in the Radial Direction	Measurements in the Vertical Direction
Ref T [℃]	T Standard Dev [mK]	T Standard Dev [mK]
30	0.66	0.67
24	0.46	0.62
20	0.73	0.43
15	0.20	0.66
10	0.35	0.46
1	0.25	0.57

Table2 The standard deviation of referencesensor at each calibration point during the temperature distribution measurement.

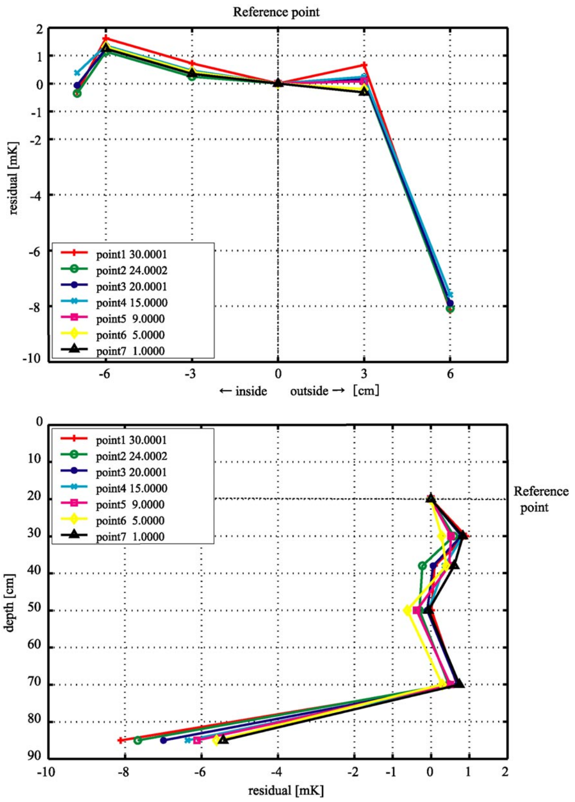

Fig.5 Temperature distribution relative to reference points. Upper panel shoes temperature distribution in radius direction, and lower panel does the same except for in vertical direction.

The temperature measurements deviated largely from the reference in the outer and lower parts of the bath due to the fact that the water inside the bath moves down through the cylinder at the center of the bath, and upward outside the cylinder. This motion causes a collision with the flow of water created by the stirrer, thereby disrupting the uniformity of the water temperature.

The error variance was calculated according to the "Rules of Calibration (JIS Z 9090),"[6] at points at which the difference from the reference was less than ±2 mK. This calibration bath was found to have a calibration-error range of ±1.7 mK.

3.4 Conclusions of the Experiment

The results of the temperature-distribution measurements show that the difference in water temperature from the reference is less than ±2 mK within a ring extending 7 cm inside and 3 cm outside the reference circle at a depth of 20 cm, and within a depth of 20 cm to 70 cm below the surface at the reference circle. The calibration-error range of this bath is approximately ±1.7 mK, and it was confirmed to have the water-temperature precision required for the Argo project.

In this experiment, we were able to perform the experiment with high precision by correcting the relative instrument error between the sensors;

however, in absolute calibration methods, the reference sensor must be of a proven precision. The shift in temperature displayed by the reference sensor used for calibration of the Triton-buoy sensors after a 5-month period is less than 1 mK, and it was concluded that this can be ignored in consideration of the calibration results for the temperature sensors. However, the sensors may display a sudden unexpected shift in sensitivity, and it was concluded that comparisons must be made with a traceable temperature sensor other than that manufactured by SeaBird to ensure that tests can be performed more reliably.

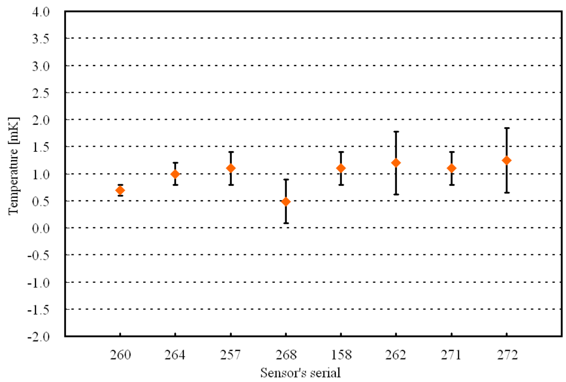

Fig.6 Average(♦) and standard deviation (error bars) of temperature difference (residuals)from reference sensor at 7 calibration.

4. Tests on Various Sensors in the Calibration Bath

4.1 Results of Test on Float Sensors (Seabird SEB41)

Of the floats deployed as of July 2001, tests were conducted on the sensors of eight floats. All sensors were SeaBird SBE41 sensors. To confirm the technological level of the test conducted at JAMSTEC, we conducted tests immediately after the sensors' arrival at JAMSTEC, and compared the results with the calibration results obtained at SeaBird. Figure 6 shows the averages and the standard deviations of the differences from the reference sensor at each temperature between 1°C and 30°C. Table 3 shows the difference in the conductivities of the reference sensor and the tested sensors at 24°C, and the salinity values calculated from the measured conductivity at 24°C. (The salinity value calculated from the conductivity will be the value at 24°C given in this paper.) From Fig. 6, it can be seen that the differences in temperature between the reference and the tested sensors are within 1 mK and the standard deviations are within 0.5 mK in the temperature range of 1°C to 30°C, so both are within the calibration-error range of the calibration bath. With the exception of the largely deviating sensor S/N0158, the precision in salinity values is higher than the 0.01 psu required by the Argo project, and the average difference in salinity (excluding S/N0158) is 0.0042 psu with a standard deviation of 0.0016 psu (Table 3). The difference in salinity values between the reference sensor and S/N0158 is large, at 0.016 psu, and this

Serial Number	Difference in Conductivity [mK/m]	/ Difference in Salinity [psu]
0252	0.61	0.0046
0268	0.34	0.0026
0260	0.39	0.0029
0264	0.43	0.0033
*0158	*2.18	*0.0165
0262	0.51	0.0039
0272	0.68	0.0052
Average Difference (excluding S/N0158)	0.56	0.0042
Standard Deviation (excluding S/N0158)	0.22	0.0016

Table3 Absolute value of deference of salinity and difference of conductivity for each sensor relative to reference sensor at 24 degree-C. The average and standard deviations for all sensors are also shown.

is believed to be due to the following. Sensor S/N0158 came with a float purchased in September 2000. The first calibration of this sensor at JAMSTEC was conducted nearly 1 year after the last calibration at SeaBird. The buoyancy of the float was adjusted 3 times between its arrival and calibration, and the sensor may have been contaminated during disassembly of the float. Four calibration tests have been conducted on sensor S/N0158 at JAMSTEC, and the difference between the observed values was
approximately 0.5 mK, so the latest test results have been used to calibrate this sensor
Matsumoto et al. (2001)[4] have pointed out that the errors in the conductivity test conducted using this

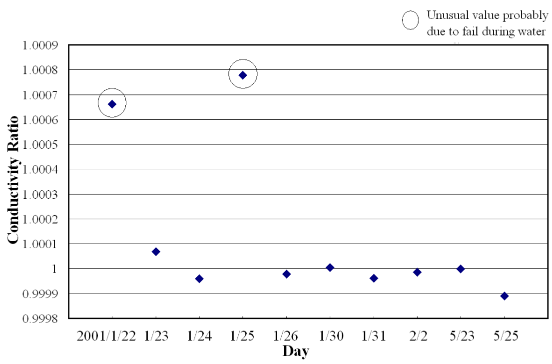

Fig.7 Conductivity ratio (correction factor to reference conductivity sensor) is shown for each calibration date, calculated as the ratio of measured conductivity to true conductivity calculated from sampled salinity measured with Autosal®. The ratio sometimes shows large difference as indicated with a large circle, in most case, such values are caused by a contamination during water sampling.

system are caused by: 1) error involving the standard seawater; 2) the thermal characteristics of the calibration bath; 3) measurements taken using the Autosal®; 4) the sampling procedure; and 5) calibration of the reference (conductivity) sensor inside the bath. There are more error factors involved in the conductivity test than in the temperature test. Furthermore, according to Matsumoto et al. (2001)[4], the difference in conductivity for SBE37-type sensors between tests conducted at SeaBird and at JAMSTEC was 0.7 mS/m at a standard deviation of 6 S/m, which is 0.006 psu when converted to salinity.

To monitor temporal shifts in the reference sensor, the correction factor is determined for the reference conductivity sensor after each test (Fig. 7). The correction factor is the ratio of the conductivity calculated from the conductivity ratio measured by the Autosal®, and the conductivity measured by the reference sensor at 24°C. The precision of the reference sensor and the accuracy of the test on conductivity can be confirmed by monitoring the correction factors. From Fig. 7, it can be seen that if the larger of the two correction factors indicated by large circles, which is the factor for Jan. 25, is used to correct the reference sensor, a difference in salinity of 0.028 psu is obtained compared to a case in which no correction was made. The salinities of water sampled in three salinity test bottles measured using Autosal® were 32.3343 psu, 32.3358 psu, 32.3328 psu, and the difference between the lowest and highest values was 0.003 psu. The Autosal® was operating stably during measurement of the standard seawater, so this difference is probably the result of a failure in the sampling itself caused by contamination of the test bottles by fresh water due to insufficient drying. Such tests are rejected and the sensors are retested.

Taking into consideration the above complexities involved in conductivity tests, the criterion for the retesting of Triton buoy sensors was set at a value deviating from the reference sensor by 0.001 S/m, with a somewhat lower calibration criterion than that for temperature. The criterion for the Argo float sensors will be set for the time being at the same value as that for Triton buoys, or 0.01 S/m, until we have accumulated a sufficient amount of data on sensor tests to set an independent criterion. Equipping the reference sensor with a pump solved the problem of air bubbles collecting on the surface of conductivity sensors in the calibration bath and causing drifts in measurements. It is therefore expected that the error in reference sensor measurements will become smaller and that the calibration criterion can be raised.

4.2 Test on the Float Sensors (FSI EXCELL-float sensor)

In addition to the SeaBird electrode sensors, the EXCELL-float inductive sensors manufactured by Falmouth Scientific, Inc., which were developed for floats, were also tested in this calibration bath. The electrode-type conductivity sensors measure the conductivity of seawater by directly passing electricity through the electrodes inside the sensor, while the inductive conductivity sensors generate electric currents around the sensor by electromagnetic induction, and detect the difference in the generated electric current according to conductivity. Depending on the sensor design, the electric field may be large in size, and it is crucial that this field be smaller than the measurable range in the test using the calibration bath, to ensure accurate salinity calibration. The reference sensor used in the test on FSI sensors was SeaBird sensor S/N2552, as in the test on SBE41-type sensors. In consideration of the field of the conductivity sensors, the sensors were placed in the center of the measurable range in the calibration bath. The measured temperature was within ±1 mK of that obtained by the reference sensor, and the temperature precision satisfied the requirements for the Argo project. However, the difference in measured conductivity between the reference sensor and the FSI sensors was significant .One factor in this difference is that the range measured by the

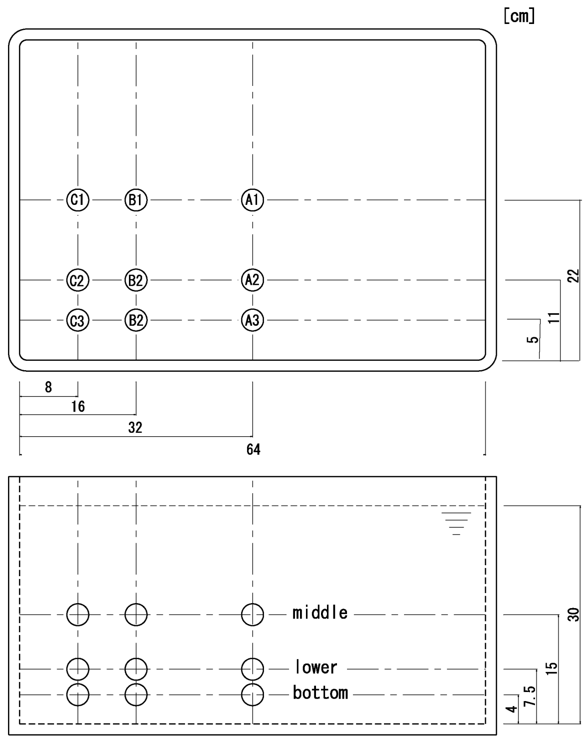

Fig.8 Location of FSI sensor for the wall effect experiment of conductivity sensor of "Inductive cell". The wall effects were measured at 9 points horizontally (A1 to C3 in the upper panel), and at 3 levels (middle to bottom in the lower panel).

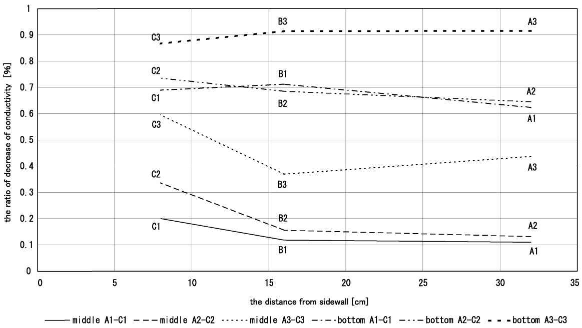

Fig.9 Results of wall effect experiment for middle layer and bottom layer. The horizontal axis shows the distance from sidewall, and the vertical axis shows the ratio of conductivity reduction

conductivity sensors exceeds the size of the bath. To confirm the measured range of the FSI conductivity sensor, an experiment was conducted using a container wider than the calibration bath, and the conductivity was measured while the distance between the container wall and the sensor was varied

The container (44 cm × 64 cm × 34 cm) was filled with salt water prepared by dissolving artificial marine salt into water. A platinum thermometer and stirrer was placed inside to create a simple bath. A total of 27 measurements were taken in the middle (9 points), lower (9 points), and bottom (9 points) layers of the simple bath, each lasting approximately 1 minute, and the measured conductivities were compared with the conductivity of the simple bath. The conductivity of the water in the simple bath was calculated from the ratio of conductivity measured by the Autosal®. Figure 8 shows the position of the sensor in the bath. Point A1 (middle layer), which is the farthest from the container wall, is located 32 cm from the front wall (shorter side), 22 cm from the side wall (longer side), and 15 cm from the bottom. The nearest point to the wall is C3 (bottom layer), which is located 8 cm from the front, 5 cm from the side, and 4 cm from the bottom. Figure 9 shows the results of measurements taken while the sensor was moved from A1 to C1, from A2 to C2, and from A3 to C3 in the middle and bottom layers. Here, we will compare the results for the middle layer, which has the best measurement conditions, and the results of the bottom layer, which is expected to have the worst conditions. Even in the A1-C1 line of the middle layer, which is believed to have the most ideal conditions, a 0.1% decrease in conductivity is observed (Fig. 9). When converted to salinity, this results in a difference of 0.03 psu. This indicates that the simple bath was not sufficiently large to confirm the extent of the range measured by the FSI sensor, and that tests on FSI sensors cannot be conducted in the even smaller calibration bath for Argo floats. The present calibration bath is sufficiently large to allow tests to be conducted on the temperature sensors of FSI floats, but a larger bath is necessary to conduct tests on conductivity sensors. The size of the range measured by the FSI conductivity sensors must first be confirmed by using larger simple baths to determine the size required for the calibration bath of inductive conductivity sensors.

5. Conclusions

The foremost goal of this paper was to clarify the thermal characteristics of the calibration bath for the Argo project, in order to determine the error range of this calibration system. The results of tests on sensors developed for the Argo floats are also presented. The following conclusions were reached in this study:

(1) The results of temperature-distribution measurements of the calibration bath show that temperature measurements can be conducted with an error range of less than ±1.7 mK within the ring extending 7 cm inside and 3 cm outside of the reference circle at a depth of 20 cm, and from 20 cm to 70 cm below the surface at the reference circle.

(2) At present, traceability can be secured for the reference conductivity sensor using standard seawater, but cannot be secured for the reference temperature sensor. To ensure reliable testing of the sensors, we plan to compare the reference temperature sensors with traceable sensors not manufactured by SeaBird.

(3) The SeaBird SBE41-type sensors have been tested for 8 floats out of all those deployed thus far. For temperature, the difference from the reference sensor averaged 1 mK with a standard deviation of 0.5 mK, at temperature points between 1°C and 30°C. The difference in conductivity from the reference sensor at 24°C averaged 0.5 mS/m (equivalent to salinity of 0.0042 psu) with a standard deviation of 0.2 mS/m (equivalent to salinity of 0.0016 psu) when sensor S/N0158 is excluded, and the precision for salinity is higher than the 0.01 psu required by the Argo project.

(4) The difference in conductivity between sensor S/N0158 and the reference sensor is 2.1 mS/m at 24°C (equivalent to 0.016 psu in salinity), which is lower than the precision required by the Argo project. Therefore, the correction factor for the latest test was used to perform calibration.

(5) In consideration of the complexities involved in the conductivity tests conducted in the calibration bath, for the time being the calibration criterion for conductivity sensors will be set at 0.001 S/m as for the Triton-buoy sensors. An independent criterion will be set when sufficient test data has been accumulated for the Argo float sensors.

(6) The calibration bath currently in use at JAMSTEC is sufficiently large to conduct tests on

FSI temperature sensors, but is not sufficiently large to conduct tests on conductivity sensors. We were unable to conduct tests on the conductivity sensors due to the fact that the measured range of the sensors was larger than the calibration bath. A larger calibration bath must be installed if we are to perform tests on FSI conductivity sensors in the future.

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