Int J Thermophys (2017) 38:164
DOI 10.1007/s10765-017-2298-3

TEMPMEKO 2016

Development of a 300 L Calibration Bath for Oceanographic Thermometers

S. Baba[1] · **K. Yamazawa**[2] · **T. Nakano**[3] ·
I. Saito[3] · **J. Tamba**[3] · **T. Wakimoto**[4] · **K. Katoh**[4]

Received: 31 August 2016 / Accepted: 4 September 2017 / Published online: 13 September 2017

Abstract The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has been developing a 300 L calibration bath to calibrate 24 oceanographic thermometers (OT) simultaneously and thereby reduce the calibration work load necessary to service more than 180 OT every year. This study investigated characteristics of the developed 300 L calibration bath using a SBE 3plus thermometer produced by an OT manufacturer. We also used 11 thermistor thermometers that were calibrated to be traceable to the international temperature scale of 1990 (ITS-90) within 1 mK of standard uncertainty through collaboration of JAMSTEC and NMIJ/AIST. Results show that the time stability of temperature of the developed bath was within ±1 mK. Furthermore, the temperature uniformity was ±1.3 mK. The expanded uncertainty ($k = 2$) components for the characteristics of the developed 300 L calibration bath were estimated as 2.9 mK, which is much less than the value of 10 mK: the required specification for uncertainty of calibration for the OT. These results demonstrated the utility of this 300 L calibration bath as a device for use with a new calibration system.

Keywords Calibration bath · Comparison calibration · Stability · Uncertainty · Uniformity · Water temperature

---

Selected Papers of the 13th International Symposium on Temperature, Humidity, Moisture and Thermal Measurements in Industry and Science.

✉ S. Baba
sbaba@jamstec.go.jp

[1] Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan

[2] Present Address: National Institute of Technology and Evaluation, Tokyo, Japan

[3] National Metrology Institute of Japan (NMIJ), AIST, Tsukuba, Japan

[4] Osaka City University, Osaka, Japan

1 Introduction

Climate change phenomena such as El Nino and monsoon phenomena are widely known worldwide. Such global phenomena are related closely to temperature changes in the air and in the ocean. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has joined in the Climate and Ocean-Variability, Predictability, and Change (CLIVAR), which is one of the four core projects of the World Climate Research Programme (WCRP) and observed and studied global phenomena using deep water moorings with oceanographic thermometers (OT) in the global moored buoy array: the international collaboration scheme. The document of CLIVAR initial Implementation Plan states that for climate trends, upper ocean temperatures require better than 0.1 °C/year accuracy on a large scale [1]. WCRP also requests moored buoy sensors in temperature to meet minimum accuracy and resolution, which are 0.02 °C and 0.001 °C [2].

To ensure such accuracy in temperature, OT must be calibrated to calibration uncertainty of 10 mK or less. In 2011, the International Committee for Weights and Measures (CIPM) strongly recommended to institutes worldwide that measurements be made fully traceable to the international system of units [3]. Therefore, calibrations of OT measuring climate change phenomena have been necessary to establish traceability to the international temperature scale of 1990 (ITS-90).

To ensure uncertainty of 10 mK or less for OT calibration, JAMSTEC calibrates them by comparison to a reference thermometer every year using a 100 L calibration bath, the present bath, produced by an OT manufacturer. Observation points in the sea for climate trends have been increasing recently to study climate change phenomena in greater detail: JAMSTEC operates more deep water moorings in the sea than ever. Consequently, the number of OT calibrations performed at JAMSTEC every year has risen to around 180. The present 100 L bath can achieve comparison calibration of up to 10 OT simultaneously and requires a long time to finish OT calibration work. We are striving to achieve simultaneous comparison calibration with many more OT to decrease the work load and to improve the calibration work efficiency.

In addition, conventional observations intended to monitor climate change have usually recorded only physical quantities such as temperatures, conductivities, or pressures at each observation point. The present 100 L bath is useful for such conventional sensors used to monitor climate change. However, observation items are now requested not only for physical quantities but also for chemical and biological quantities such as dissolved oxygen, pH, turbidity, or the number of plankton because acidification of the sea has become an important and widespread phenomenon. To obtain various observation data, nowadays we also use large devices [4] that comprise sensors measuring temperature, pressure, dissolved oxygen, pH, and so on. Because the new devices are larger and because they include many more sensors than the original devices, it is not possible anymore to calibrate the temperature sensors in the present 100 L bath without demounting them from the device.

The basic principles of calibration baths are widely known [5–7]. Manufacturers today produce various calibration baths. However, the capacity of commercial calibration baths, which can accommodate comparison calibration with thermometers with 10 mK or less uncertainty, is no greater than 50 L. Commercial calibration baths are smaller than they must be for oceanographic sensors. Therefore, to calibrate large sensors and numerous sensors simultaneously, we started developing a 300 L calibration bath for OT calibration: our developed bath. For an earlier study, we evaluated the developed bath characteristics with no OT in the bath. In that case, the 300 L calibration bath showed time stability of temperature within ± 1 mK and also showed uniformity of temperature in the calibration area within ± 3 mK [8]. Although the characteristics of the 300 L calibration bath seem to have sufficient capability for the calibration of thermometers within uncertainty of 10 mK, our earlier study did not assess effects on the temperature stability of devices under testing, specifically OT, that had been set in the bath.

This study investigated the time stability and uniformity of temperature when we set 24 OT in the bath. As described in this paper, as a primary step to check the capabilities of the developed bath, we examined the time stability and uniformity of temperature at 24 °C, a temperature that is often observed during our sea observations. We also evaluated uncertainty components for the characteristics of the developed bath for OT calibration.

2 Experimental Apparatus and Procedures

2.1 Design of the Developed Calibration Bath

Figure 1 presents a schematic diagram of the 300 L calibration bath we developed for OT calibration. We designed this developed bath based on the present 100 L calibration bath. The time stability of temperature in the present bath is within ± 1 mK [9]. For water tank '1' in Fig. 1, we used a commercial water tank (SUS316L, 635 mm inner diameter, 1200 mm depth) that has the target volume. The 50 mm thick thermal insulation (thermal conductivity of $0.037\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$) is attached to its outer wall. We use water as the thermal fluid of the developed bath to produce a stable temperature state.

The water level in the water tank is 1000 mm. Motor '2' in Fig. 1 rotates the two impellers '3' (4 blades, 71.5 mm blade diameter) in inner pipe '4' (140 mm outer diameter), which is in the center of the water tank, at 1000 rpm producing a downward flow in the inner pipe. The flow is exhausted from the clearance at 60 mm height made by cross plate '5' at the bottom of the bath. Then the flow passes along the bottom of the water tank. Some flow rises up by the 60 mm high guide vane '6', with 35.4 % in perforations at 130 mm radius at the bottom of the water tank. The remainder of the flow continues to move along the bottom of the water tank, after which it rises up along the water tank wall. Each flow then reaches calibration area '7' (350 mm to 650 mm height from the bottom of the water tank), where the OT sensing elements are set for calibration. The flow then passes into opening '8' at 120 mm height and circulates.

For the calibration of OT using the present bath, we used a thermometer (SBE 3plus; Sea-Bird Electronics, Inc.), the sensor of which is a thermistor made by the OT manufacturer, as a reference thermometer. It has a stainless steel sheath (ϕ0.8 mm diameter, 56 mm length). The thermistor element is at the sheath edge. An electrical circuit in the body converts resistance values of the thermistor element to frequency

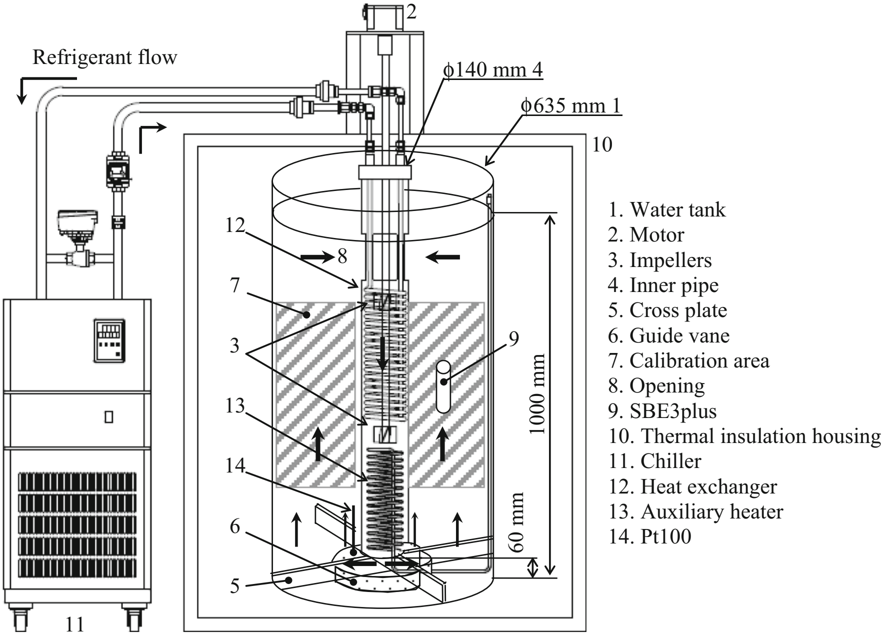


Fig. 1 Schematic showing the developed experimental calibration bath

signals. The SBE 3plus thermometer is calibrated by the manufacturer every year to be traceable to the ITS-90 of the accuracy within ±1 mK. For the developed bath, the SBE 3plus thermometer ‘9’ in Fig. 1 is also used as a reference thermometer for calibration. It is at the center of the calibration area: 194 mm from the center of the water tank and 500 mm up from the bottom of the water tank.

To reduce the influence of temperature variation around the water tank, a polyvinyl chloride lid with 5 mm thick thermal insulation (thermal conductivity, $0.037\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$) covers the top of the bath. In addition, the whole water tank itself is covered with 1.2 m square thermal insulation ‘10’ with 50 mm thick insulation (thermal conductivity, $0.037\ \mathrm{W \cdot m^{-1} \cdot K^{-1}}$).

The water volume in the developed bath is three times that of the present bath. Therefore, the cooling capacity of chiller ‘11’ of the developed bath (cooling capacity, 2.9 kW) is three times that of the present bath. The chiller can control the temperature of its refrigerant at temperatures of $-10\,^{\circ}\mathrm{C}$ to $80\,^{\circ}\mathrm{C}$. The temperature stability of the refrigerant is within ±50 mK. It roughly controls the temperature of water in the water tank by injecting the refrigerant through the coiled heat exchanger ‘12’ (SUS304 pipe, ϕ10 mm inner diameter, 10 m length). Furthermore, to bring the temperature of water in the bath to a stable condition, with temperature stability in the water tank within ±1 mK, we use the auxiliary heater ‘13’ (100 W maximum output, ϕ 2.3 mm sheath outer diameter, 4.4 m length), which is set under the heat exchanger. The heater power of the auxiliary heater is controlled using a proportional–integral–differential (PID) controller to reach a stable state of the water temperature within ±1 mK. The four-wire resistance thermometer Pt100 ‘14’ (ϕ 4.8 mm sheath outer diameter), used for measuring water temperature and to control it, is set at the inner-pipe outlet.

The calibration temperature range is 1 °C to 32.5 °C because the target range for water temperature measurements in the sea is 5 °C to 30 °C. The water flow pattern in the developed bath is forced convection because the two impellers in the water tank agitate water there. We assume that the uniformity of temperature at each of calibration temperatures, 1 °C to 32.5 °C, exhibits a similar tendency due to the fact that the flow pattern in the water tank is qualitatively similar to that at 24 °C. As described in this paper, as a primary step, we specifically examined the time stability and uniformity of temperature in the bath at 24 °C, which is often observed during our sea observations and which is close to room temperature around the bath. We have been examining them sequentially at each calibration temperature.

When we conduct practical calibration of the OT, the bath is first heated to a higher temperature in the range of calibration temperatures. Then, it is cooled to a target calibration temperature to prevent bubbles from attaching to the OT sensing elements. For this study, the bath is first heated to temperatures higher than 25 °C. The bath is then cooled until readings from the SBE 3plus reference thermometer reach 24 °C. Furthermore, when both the following two conditions are satisfied, comparison calibration will be completed. The standard deviation of the readings from the SBE 3plus for 10 min (100 measuring points) is within 1 mK. Additionally, the time stability of the readings from the SBE 3plus for the same period is within ±1 mK. These conditions are the same as those used for calibration using the present bath.

2.2 Arrangement of the OT in the Developed Bath

Figure 2 presents the arrangement of the OT in the developed bath in this study. The 24 OT are set in the bath. We are planning the same arrangement of the OT for their calibration.

An OT has a titanium pressure vessel (ϕ 62.2 mm diameter; 420 mm length) to protect measurement devices from high water pressure in the deep sea. The pressure vessel also encloses batteries and electrical circuits for temperature measurements. The temperature sensing element (thermistor) is mounted inside a small sheath (2.2 mm diameter, 12 mm length) that protrudes in the axial direction of the pressure vessel of the OT at 48 mm from the end of the pressure vessel. Furthermore, to prevent the sensing element of the device from touching any float in the sea, the sheath is surrounded by a cover that is 40 mm distant from the surface vessel and 395 mm long.

The sensing elements of eight OT are on the ϕ 340 mm diameter inner circle. The remainder are on the ϕ 435 mm diameter outer circle of the water tank. Sensing elements of both the OT and of SBE 3plus are set at the same height of 500 mm from the bottom of the water tank.

2.3 Measurement of the Time Stability and the Uniformity of Water Temperature in the Bath

To confirm the time stability of temperature in the bath, we used a SBE 3plus thermometer to measure the water temperature. We also use a system with 11 thermistor

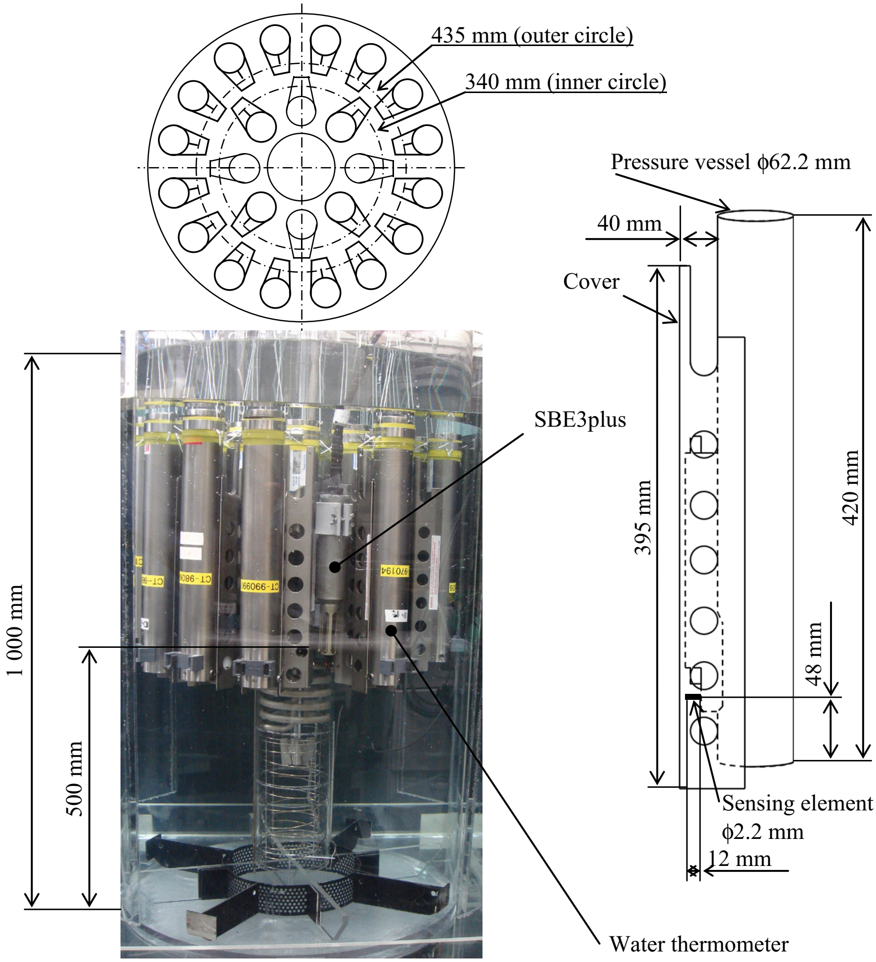
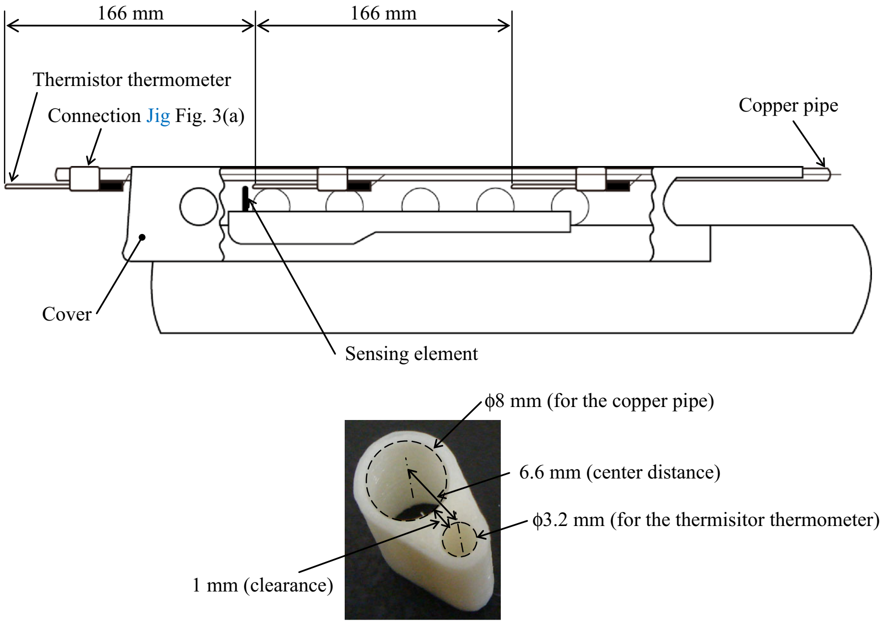


Fig. 2 Arrangement of the 24 OT in the developed bath for calibration of the OT

thermometers made to check the time stability and uniformity of the water temperatures in the developed bath. These thermistor thermometers were calibrated to be traceable to the Japanese national standard of temperature using the method described in the earlier study [8]. We used the same calibration bath (Fig. 3 of Ref. [8]) and made a comparison calibration between the SPRT and 11 thermistor thermometers. The ϕ 30 mm diameter isothermal block was put in the center of the bath. It has one well in its center for the SPRT and 12 wells around the center well for thermistor thermometers. The maximum in-plane distance among the thermistor thermometers is 22 mm. The difference between the sensing element of SPRT and thermistor thermometer in the depth direction is 5.7 mm. The thermistor thermometer has a ϕ 3.2 mm diameter and 76.3 mm long sheath (Fluke Corp.). Their reading device is a special readout unit and scanner for these thermistor thermometers. We estimated the stan-



(a)

Fig. 3 Schematic showing the setting of thermistor thermometers beside the OT. (a) Connection jig between the copper pipe and the thermistor thermometer

dard uncertainties relative to the thermistor thermometers as follows. The resolution is 0.1 mK from the value listed in its catalog. We measured errors of the thermistor thermometer, readout unit and scanner during the calibration, which came to 0.27 mK in standard deviation, with 40 measuring points. The influence of self-heating from the thermistor thermometer is expected to be negligible because its self-heating is 1 μW, which is much less than that of SPRT. The stability of the thermistor thermometers, which was within ±1.25 mK, resulted from the difference calibration between before and after the measurement of the time stability and uniformity of temperature in the developed bath. Assuming that this value is a rectangular distribution, we defined 0.72 mK as the uncertainty due to the stability of the thermistor thermometers. This value is the largest uncertainty component for thermistor thermometers in the calibration. In addition, the uncertainty due to the SPRT was 0.43 mK. Furthermore, the uncertainty due to the comparison calibration bath was 0.37 mK including the temperature stability of the isothermal block (±0.5 mK with rectangle distribution), temperature distribution along the thermometer well (±0.1 mK with rectangle distribution), and temperature difference among the various thermometer wells (±0.4 mK with rectangle distribution) we measured. We combined these standard uncertainties and caused 0.92 mK the expanded uncertainty of thermistor thermometers at 24 °C.

Figure 3 shows thermistor thermometers setting along the OT. Three thermistor thermometers are fixed to the copper pipe, which has ϕ 8 mm diameter, 450 mm length, and 160 mm pitch. To fix the thermistor thermometer to the copper pipe, we made a special connector jig (Fig. 3a) made from ABS thermoplastic (thermal conductivity 0.1–0.3W $\cdot$ m^{-1} $\cdot$ K^{-1}), which has two 20 mm length through wells in the diameter of the copper pipe (ϕ 8 mm) and thermistor thermometer (ϕ 3.2 mm), respectively, with 6.6 mm pitch. This pitch gives 1 mm clearance between the copper pipe and thermistor thermometers, when they are fixed threading through the wells of the jig. Then, the copper pipe with three thermistor thermometers is set inside the cover of the OT adjusting the position of the center of the three thermistor thermometers to the position of sensing element of the OT. The sensing element of the OT is at 500 mm height from the bottom of the water tank so that the three thermistor thermometers are, respectively, 333 mm, 500 mm and 666 mm height from the bottom of the water tank. These measurement positions in the depth direction are the same as those reported from an earlier study [8] that measured the uniformity of the temperature in the bath with no loads. As described above, the 11 thermistor thermometers are set with the four OT. One of those OT is equipped only with two thermistor thermometers at 500 mm and 666 mm height from the bottom of the water tank. The four OT are set at any of the 24 positions shown in Fig. 2. The thermistor thermometers measure temperatures where they are in the bath.

3 Results and Considerations

In this study, using results obtained using the SBE3plus and 11 thermistor thermometers in the developed bath at 24 °C to estimate the uncertainty components for the time stability and uniformity of temperature, the following three uncertainty components were estimated: (1) the time stability of temperature in the bath, (2) the uniformity of temperature along the depth direction in the bath, and (3) the uniformity of temperature around the circular direction in the bath.

3.1 Uncertainty Due to the Time Stability of Temperature in the Bath

The water temperature in the bath is controlled to 24 °C. After it becomes stable, the SBE 3plus thermometer was used to measure the temperature variation in the bath for 10 min, which is necessary for comparison calibration. Figure 4 presents highlights of the results. The horizontal axis shows the elapsed time for 10 min. The vertical axis shows the temperature deviation from the reference temperature defined as (maximum value–minimum value)/2 for 10 min. Figure 4 shows the time stability of temperature of within ±1 mK in the bath measured using the SBE 3plus thermometer as the reference thermometer.

Figure 5 presents the time variation of temperature observed using each thermistor thermometer, which is 500 mm from the bottom of the water tank, while the readings from SBE 3plus are within ±1 mK. The vertical axis presents the temperature deviation from the reference temperature defined as (maximum value–minimum value)/2 for 10 min as well as Fig. 4. The ◇ and ○ symbols in the graph, respectively, denote readings from the four thermistor thermometers on the inner and outer circles in the bath every 90° at the same time for 10 min. The same symbols in Fig. 4 (◇, ○) are readings from SBE 3plus during the same measurement time. Results obtained using

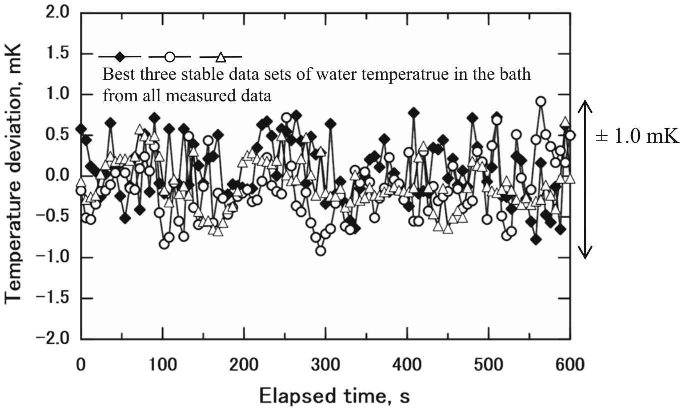


Fig. 4 Variation of the water temperature measured using the SBE3plus in the bath for 10 min after the water temperature becomes stable at 24 °C

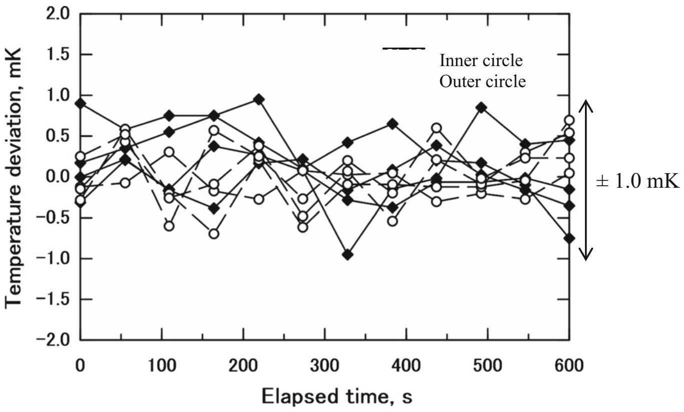


Fig. 5 Variation of the water temperature measured using thermistor thermometers at 500 mm height from the bottom of the bath for 10 min after the water temperature becomes stable at 24 °C

the thermistor thermometers also show that the time stability of temperatures in the bath at 500 mm from the bottom of the bath is within ±1 mK. According to results obtained using both SBE 3plus and the thermistor thermometers, as shown in Figs. 4, 5, the standard uncertainty due to the time stability of temperature in the bath is estimated as 0.58 mK, assuming this variation of the temperature as a rectangular distribution.

3.2 Uncertainty Due to the Uniformity of Temperature Along the Depth Direction in the Bath

Figure 6 presents temperature uniformity along the depth direction in the bath. The horizontal axis shows measurement positions of the thermistor thermometers in the bath. A certain position on the outside edge of the bath is designated as *zero*. The same

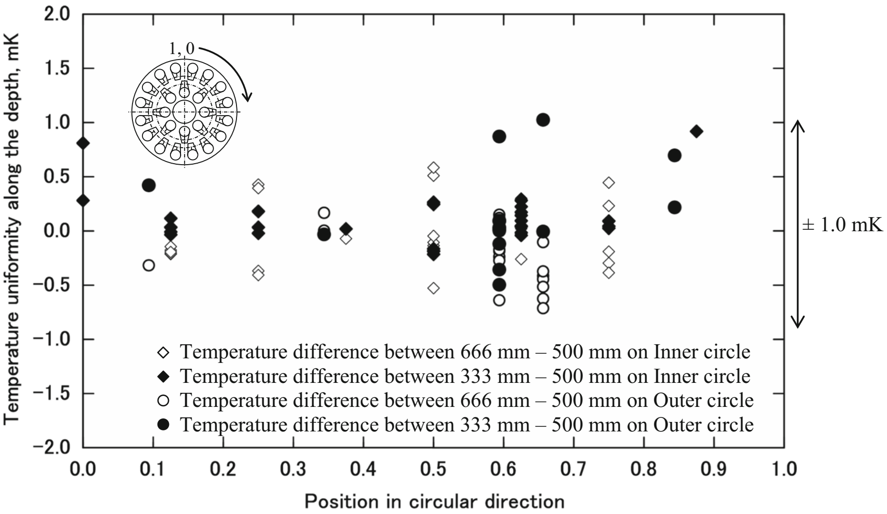


Fig. 6 Temperature uniformity along the depth direction in the developed bath at 24 °C

position clockwise going around the edge of the bath is designated as *one*. The vertical axis shows the different temperatures observed by the thermistor thermometers at 666 mm (the upper area of the water tank) and those at 333 mm (the lower area of the water tank) from that observed using the thermistor thermometers at 500 mm for each position. The white and black marks, respectively, denote temperature differences obtained at the upper area and the lower area of the water tank. Diamond marks are readings for the inside circle. Circle marks are readings on the outside circle. The temperatures were obtained by averaging the readings from each thermistor thermometer for 10 min, while the SBE 3plus shows stable temperatures within ±1 mK. The figure shows that the uniformity of temperatures along the depth in the bath is within ±1 mK. The standard uncertainty due to the temperature uniformity along the depth direction in the bath is estimated as 0.58 mK, assuming a rectangular distribution.

3.3 Uncertainty Due to the Uniformity of Temperature Around the Circular Direction in the Bath

Figure 7 presents results of the uniformity of temperature around the circular direction in the bath. The horizontal axis presents measurement positions of thermistor thermometers in the bath, defined similarly to Fig. 6. The vertical axis shows differences of temperatures observed using a thermistor thermometer at 500 mm height from the bottom of the bath from the average of the other ten thermistor thermometers. The temperatures are average values measured using the thermistor thermometers for 10 min, while the SBE 3puls maintains a stable temperature within ±1 mK. The ◇ symbols in the graph denote readings from the thermistor thermometers on the ϕ 340 mm diameter inner circle. The ∘ symbols denote readings from the ϕ 435 mm diameter outer circle in the bath. The figure shows the uniformity of temperature around circular direction

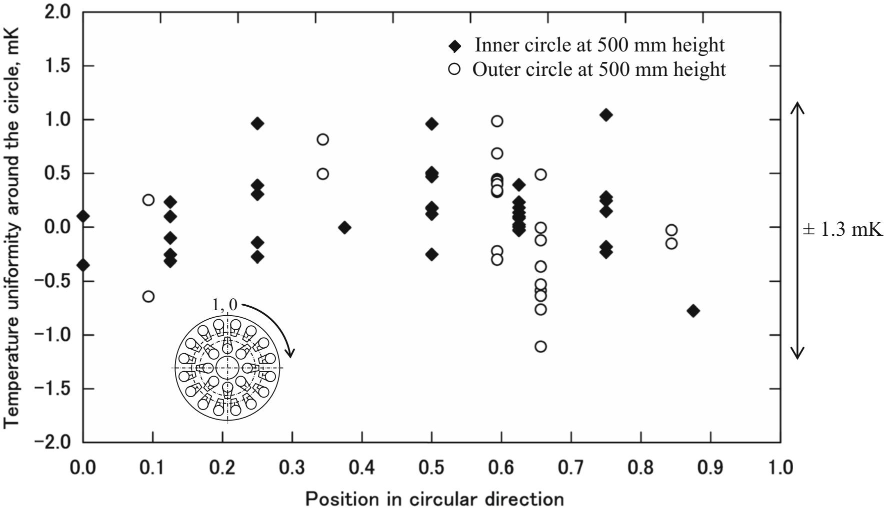


Fig. 7 Temperature uniformity around the circular direction at 500 mm height in the developed bath at 24 °C

Table 1 Uncertainty of the temperature realized in the measurement area when the developed bath is loaded with the 24 calibrated oceanographic thermometers and one reference thermometer at 24 °C

	Standard uncertainty (mK)
Uncertainty due to items being measured and the measuring process	
(a) Time stability	0.58
(b) Temperature uniformity along the depth	0.58
(c) Temperature uniformity at the 500 mm level	0.75
Uncertainty related to the temperature measuring device	
(d) Calibration and stability of thermistor thermometers	0.92
Combined standard uncertainty	1.44 ($k = 1$)
Expanded uncertainty	2.9 ($k = 2$)

at 500 mm height from the bottom of the water tank to within ±1.3 mK. The standard uncertainty due to temperature uniformity around the circular direction is estimated as 0.72 mK, assuming a rectangular distribution.

3.4 Uncertainty Budget

Table 1 presents uncertainty budget components for characteristics of the developed bath when loaded with 24 OT devices during testing at 24 °C, with one reference thermometer. When evaluating the measurement uncertainty according to the guide to the expression of uncertainty in measurement [10], this standard uncertainty results in 1.44 mK of the combined standard uncertainty ($k = 1$). The expanded uncertainty ($k = 2$) for a confidence interval of 95 % is 2.9 mK. However, as described for the earlier study [8], the result of the uniformity of temperature without loads in the bath is ±0.71 mK. Furthermore, this result, added to the uncertainty due to the thermistor thermometers themselves, gives expanded uncertainty (k = 2) of 1.76 mK. Comparison of the results obtained for this study reveals that the difference of expanded uncertainty is 1.1 mK, which is probably due to the 24 OT obstructing the flow in the bath and deterioration of the agitating intensity and the uniformity of the temperature in the bath.

4 Conclusions and Future Plans

As described in this paper, we have been developing the 300 L calibration bath for the calibration of OT, which are used to measure the variation of seawater temperatures with 0.1 K uncertainty. We also verified the uncertainty components for characteristics of the developed bath for OT calibration. To evaluate the uncertainty, we measured the time stability and uniformity of temperature in the developed bath with the 24 OT as devices under testing and the SBE 3plus as a reference thermometer at 24 °C, a temperature that is commonly encountered during our sea observations. The following three points were supported by temperature measurements conducted in the bath.

- Temperature time stability measured using the reference temperature of the SBE 3plus thermometers and thermistor thermometers at 500 mm from the bottom of the water tank is within ±1 mK.
- Temperature uniformity measured using the thermistor thermometers along the depth distance in the calibration area of the water tank is within ±1 mK.
- Temperature uniformity around the circular distance of the water tank measured by the thermistor thermometers at 500 mm from the bottom of the water tank is within ±1.3 mK.

We estimate the expanded uncertainty ($k = 2$) components for those characteristics of the bath as 2.9 mK. In addition, the expanded uncertainty is sufficiently small: less than the value of 10 mK requested as the uncertainty of calibration for the OT when observing sea temperatures. Above all, the results of this study indicated that the developed bath has sufficient capability for use with our calibration procedures.

For this study, we conducted experiments only at 24 °C water temperature in the bath. We plan to verify the uncertainty components for bath characteristics at different temperatures of 1 °C to 32.5 °C.

The reference thermometer used for our calibration procedures, SBE 3plus, is calibrated by the manufacturer to conform to national measurement standards in the USA. That process takes 4 months for calibration. We hope to calibrate the reference thermometer to the Japanese national standard at NMIJ/AIST to reduce the calibration time. In the near future, we expect to establish a calibration system for the SBE 3plus within 1 mK uncertainty to conform to the Japanese national standard. In addition, using the developed bath, we expect to develop a new calibration procedure for OT, providing uncertainty within 10 mK.

Acknowledgements We greatly appreciate comments related to the scientific background of this study by Iwao Ueki. We also thank Shoko Tatamisashi and Koki Uda (Marine Works Japan Ltd.) for operating this calibration bath and for assisting with temperature accuracy measurements in the bath.

References

1. Climate and Ocean–Variability, Predictability, and Change, CLIVAR Initial Implementation Plan, pp. 38 (1998). http://www.clivar.org/node/255. Accessed 02 Feb 2017
2. World Climate Research Programme, WCRP Informal Report No. 5, pp34 (2006). http://www.pmel.noaa.gov/gtmba/files/rama/IndOOS_Plan.pdf. Accessed 02 Feb 2017
3. Bureau International des Poids Measures, 24th Meeting (2011) Resolutions 2. http://www.bipm.org/en/CGPM/db/24/2/. Accessed 16 August 2016
4. Sea-Bird Electronics, Inc., Profiling CTDs: SBE 911plusCTD: Documents: 911plusbrochure-Jun16.pdf. http://www.seabird.com/sites/default/files/documents/911plusbrochureJun16.pdf. Accessed 16 August 2016
5. R.E.G. Webb, H.T. Robinson, J. Phys. E: Sci. Inst. **6**, 27–29 (1973)
6. T. Saino, K. Koizumi, S. Amano, Bull. NRLM **29**, 21–26 (1974)
7. Fluke Incorporated, Temperature calibration equipment and services (2008), pp. 112–113
8. S. Baba, K. Yamazawa, J. Tamba, T. Wakimoto, K. Katoh, Trans. JSME **81**, 1–14 (2015). [**in Japanese**]
9. T. Matsumoto, T. Nagahama, K. Ando, I. Ueki, Y. Kuroda, Y. Takatsuki, JAMSTECR **44**, 139–151 (2001). [**in Japanese]**
10. Guide to the Expression of Uncertainty in Measurement, Evaluation of measurement data–Guide to the expression of uncertainty in measurement, Bureau International des Poids Measures, JCGM 100: (2008), (GUM 1995 with minor corrections), pp. 1–26