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The Latest Batch-to-batch Difference Table of Standard Seawater and Its Application to the WOCE Onetime Sections

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An updated batch-to-batch difference table of IAPSO standard seawater (SSW) up to P145 is proposed. The batch-to-batch difference table is based on several recent SSW comparison experiments, including the experiments conducted independently at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Woods Hole Institute of Oceanography (WHOI) at about the same time using the same procedure. Proposed batch-to-batch differences range from 1.2×10^{-3} to -1.9×10^{-3} with reference to the average of those from P91 to P102. Batch-to-batch differences from P29 to P145 with reference to the recent batches and this average over every 5 years since 1960 are also presented, together with standard deviation. This reveals that inconsistency among batches has improved since 1980s. In particular, the standard deviation was 0.3×10^{-3} in this decade, which is about one-half the value reported previously and almost equal to the modern measurement precision (0.2×10^{-3}) and is within-batch difference ($<0.3 \times 10^{-3}$). Proposed batch-to-batch differences were applied to the observational results of the WOCE hydrographic onetime section (WHP onetime) in the Indian Ocean. Average absolute salinity differences at 14 crossover points in the Indian Ocean were slightly larger, from 1.2×10^{-3} to 1.5×10^{-3}, when the batch-to-batch difference table was applied; however, when results from the Indian, Pacific, and Atlantic Oceans were combined, application of the batch-to-batch difference table yielded statistically acceptable salinity differences. The table was also applied to WHP sections P1 and P17 (revisited about 10 years after the original observations during the WOCE period) and sections I1, I7, and I8 (visited twice by different research vessels in the same year). In all cases, the table corrected unrealistically large salinity changes in space and time. The results suggest that the application of the batch-to-batch table to well-controlled salinity data such as WOCE datasets would be effective in making the datasets more consistent in space and time.

Keywords:
· Standard seawater,
· salinity,
· batch-to-batch difference,
· WOCE,
· CLIVAR.

1. Introduction

In the early 1990s, a series of trans-oceanic high accuracy hydrographic observations was conducted as part of World Ocean Circulation Experiment (WOCE). Recently, hydrographic observations at the same stations were conducted as part of CLIVAR/CARBON. Comparison of salinity distributions is an interesting and important issue in the investigation of the decadal change of freshwater transport. However, great attention should be paid to comparing salinity measured during different cruises, especially in the deep, where salinity change is supposed to be small.

The salinity of seawater has been defined in terms of the ratio of its electrical conductivity (at temperature

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15°C and one standard atmosphere pressure) to the conductivity of a potassium chloride solution in which the mass fraction of potassium chloride is 32.4356×10^{-3} (hereafter referred to as the PSS78 Standard Solution) at the same temperature and pressure (UNESCO, 1981a). The International Association for the Physical Sciences of the Ocean (IAPSO) standard seawater (SSW) is widely used for oceanographic observations. The label on each ampoule of SSW contains information on the SSW electrical conductivity ratio and salinity according to the Practical Salinity Scale of 1978 (PSS78). However, studies (e.g., Mantyla, 1980, 1987, 1994) have shown differences among SSW batches. The main cause of batch-to-batch differences among batches P1–P90 (calibrated in chlorinity) was the variation in the relationship between chlorinity and conductivity. Takatsuki *et al.* (1991) reported that batch-to-batch differences still exist but are greatly reduced (to about 0.5×10^{-3} in salinity) when calibration is based on conductivity. Aoyama *et al.* (1998, 2002) collected results of SSW comparisons from various institutions and created a table of batch-to-batch differences for batches P91 to P129. They used batches P94 (prepared in 1984), P110 (1988), P123 (1992), and P124 (1993) as key batches to harmonize the experimental results reported by various institutions in the period 1991 to 1997, under the assumption that the SSW did not change appreciably during this period. Kawano *et al.* (2001) tried to extend this table to P140. Although the authors call this table of relative differences the "offset table", the values in the table are neither errors nor offsets from "true" salinity but relative differences among batches, because the value described in the table corresponds to the difference between Mantyla's standard (the average of batch-to-batch differences from P91 to P102) and the measured value. Their hypothesis is that the batch-to-batch differences reported by various studies such as Mantyla (1994) and Takatsuki *et al.* (1991) reflect, to a considerable extent, differences at the time of preparation of the SSW (initial offset).

Recently, Kawano *et al.* (2005) prepared defined solutions using several batches of high-purity potassium chloride and examined the differences between the measured electrical conductivity ratios and the values calculated from the experimental equation given in the UNESCO background papers (UNESCO, 1981b). They found that differences among the electrical conductivity ratios of the solutions made from various potassium chloride reagents were equivalent to about 1.2×10^{-3} in salinity, suggesting that the initial offset of SSW was attributable to the lot dependency of the electrical conductivity ratios of the potassium chloride solutions.

On the other hand, changes in the conductivity of the SSW have long been thought to be a result of an aging effect (such as microbial activity or interaction between seawater and glass ampoules) after preparation of the SSW. If changes in SSW conductivity were caused almost entirely by aging, retrospective application of the batch-to-batch difference table would be inappropriate, because batch-to-batch differences seen in a SSW comparison experiment are only a reflection of salinity changes at the time of the experiment. Culkin and Ridout (1998) demonstrated that SSWs with batch numbers P120 to P129 showed differences of less than 1×10^{-3} in salinity against the defined KCl solution during storage periods of up to 96 weeks. Bacon *et al.* (2000) analyzed salinity data collected during seven cruises between 1991 and 1997. Using the value given by Culkin and Ridout (1998), they calculated the temporal salinity changes of SSW and cautioned against the uncritical application of the table of batch-to-batch differences. As an example of aging effect, Bacon *et al.* (2000) showed that the difference between measured and label salinity values of SSW batch P128 (prepared in 1995) was 1.5×10^{-3} to 2.0×10^{-3} when the batch was 25 months old (although the difference was given as 0.1×10^{-3} in Aoyama *et al.*, 1998). Bacon *et al.* (2000) asserted that a simple correction like that of Aoyama *et al.* (1998) was not appropriate, and concluded that the crucial factor in assessing inter-cruise salinity differences in terms of SSW is the age of SSW at the time of use. Bacon *et al.* (2000) speculated that Aoyama *et al.* (1998) had measured the salinity of SSW batch P128 shortly after it was prepared, but Aoyama *et al.* (2002) explained that those measurements were made in May 1997, when SSW batch P128 was 22 months old. The discrepancy between the values found by Aoyama *et al.* (1998) and Bacon *et al.* (2000) is caused by the use of different references: as mentioned previously, the values in the batch-to-batch difference table of Aoyama *et al.* (1998) are not derived from comparison with PSS78 Standard Solution nor a single batch of SSW but rather the average batch-to-batch difference of P91 to P102, while Bacon *et al.* (2000) used SSW batch P132 as reference. The effect of this different reference can be seen by comparing the values for P116, P120, P121, P124, and P128 found in table 2 of Bacon *et al.* (2000) and table 4 of Aoyama *et al.* (2002). There is only one measurement in Bacon *et al.* (2000) for P121, P124, and P128. When we treat the results for P116 and P120 as a SSW comparison experiment and average the values, it becomes 1.5×10^{-3} for P116 and -0.7×10^{-3} for P124. They shift parallel to batch-to-batch differences of Aoyama *et al.* (2002) due to the difference of the reference, which indicates that batch-to-batch differences estimated from both results are relatively equivalent.

Gouretski and Jancke (2001) conducted an analysis of salinity batch-to-batch difference among global hydrographic datasets, including WOCE results. They applied the batch-to-batch difference table of Aoyama *et* *al*. (1998) to 299 cruise pairs (all data), namely, WOCE only (131 pairs), WOCE/non-WOCE (111 pairs), and non-WOCE (57 pairs). The average absolute batch-to-batch difference was lower in the all-data and WOCE pairs and higher in the other two datasets. The authors point out the discouraging inability of simple batch corrections to reduce inter-cruise salinity differences without taking batch aging into account, and that uncertainties in the label SSW salinity remain a source of inter-cruise salinity differences. The simple batch correction may be effective only for the WOCE dataset because the systematic error due to differences in measurement technique was greatly reduced for the WOCE project. As mentioned by Mantyla (1994), the systematic error of salinity (inter-cruise salinity difference) is caused by the use of different salinometer settings and water samplers, different periods between sampling and analysis, and so on. Such problems were minimized for the WOCE dataset, since the procedure from sampling to analysis presented in detail by Stalcup (1991) was used exclusively by WOCE participants. A more important aspect of the effect of the application of the batch-to-batch difference table is discussed by Aoyama *et al*. (2002), who clearly demonstrated that deep salinity differences at the crossover points of the onetime survey line of the WOCE Hydrographic Program (WHP) in the Pacific and the Atlantic were significantly reduced when the batch-to-batch difference table was applied. Their results suggest that differences in salinity after applying the batch-to-batch difference table arise mostly from the random error of salinity measurements. Fukasawa *et al*. (2004) applied the batch-to-batch differences given by Kawano *et al*. (2001) and Aoyama *et al*. (2002) to salinity observed along WHP line P1 (mainly along 47°N) and noted that the separate segments of the survey did not match in the deep water until batch corrections were made.

Since Mantyla (1987) recommends continuous monitoring of SSW batch-to-batch comparisons by more than one laboratory, in the study reported here we performed independent SSW comparison experiments at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Woods Hole Institute of Oceanography (WHOI) at about the same time using the same procedure. Using these results and the outcomes of other recent comparison experiments, we have updated the table proposed by Kawano *et al*. (2001) and expanded the batch-to-batch difference table of Aoyama *et al*. (2002) to batch P145. Since values of P113, P115, P117, P125, and P126 are not recorded in the table of Aoyama *et al*. (2002), we tried to fill some of the blanks using the results of Bacon *et al*. (2000) and Culkin and Ridout (1998). We also applied the expanded table to the WOCE results to demonstrate its effectiveness in making salinity differences more consistent.

2. Cross-Laboratory Comparison Experiment

Comparison experiments on some recent SSW batches were performed at JAMSTEC and WHOI in 2002, 2003, and 2005.

2.1 Comparison experiment at JAMSTEC

Double conductivity ratios were measured for 7 batches of SSW (total of 55 ampoules) on 30 May 2002, 9 batches (58 ampoules) on 14 July 2003, and 11 batches (59 ampoules) on 25 March 2005 in an air-conditioned laboratory at JAMSTEC. Measurements were made using an Autosal laboratory salinometer Model 8400B manufactured by Guildline Instruments. The method of measurement used at JAMSTEC is described in Aoyama *et al*. (2002). The Autosal was calibrated before each measurement according to the service manual for the instrument (Guildline Instruments, 1991). The bath temperature of the Autosal (24°C) was essentially constant during the measurements. The Autosal was standardized with SSW batch P142. In order to avoid any discontinuity that might be caused by different settings (Mantyla, 1987), the suppression dial was set at "2.0" for all measurements.

2.2 Comparison experiment at WHOI

Double conductivity ratios were measured for 7 SSW batches (total of 45 ampoules) on 28 July 2002, 10 batches (70 ampoules) on 3 August 2003, and 9 batches (56 ampoules) on 14 April 2005 in an air-conditioned laboratory at WHOI. Attempts were made to duplicate the JAMSTEC procedure as closely as possible, but there were differences in data acquisition and measurement procedure. The data from a sample was acquired every 1.3 seconds for about 40 seconds (31 measurements per sample), while it took about 10 seconds for 31 measurements in JAMSTEC. Similar to the procedure in JAMSTEC, measurements were made on the 3rd, 4th, and 5th flushes. However, when the 3rd flush was full, we turned off the pump, turned the function switch to "Read", and allowed the sample to incubate for 30 seconds, while this was not allowed in JAMSTEC. We found this process necessary due to drift caused by self-heating of the sample as current passed through the electrodes. Drift stopped after about 30 seconds. This procedure was also used for the standardization process using SSW batch P142. The air temperature shown for each flush is the average of the temperature at the beginning and the end of the 40-second reading period. Bath and air temperatures were measured with a Hart Scientific Model 1575 4 PPM Superthermometer. The salinometer used was the same model as that of JAMSTEC (Guildline Autosal Model 8400B). The bath temperature (24°C) was essentially constant during the measurements. The suppression dial was set at "1.9" for all measurements.

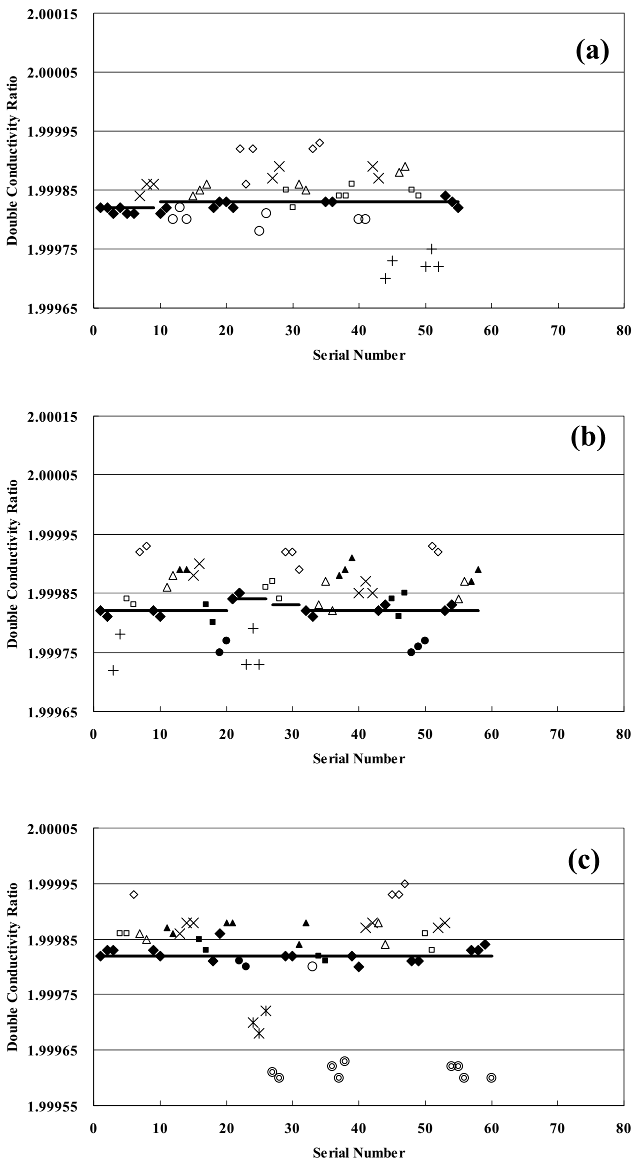

Fig. 1. Results of comparison experiments by JAMSTEC (a) in 2002 (b) in 2003 and (c) in 2005. Plus (+) represents data for P133, square (□) P135, diamond (◇) P136, triangle (△) P137, cross (×) P139, circle (○) P140, solid square (■) P141, solid diamond (◆) P142 (reference), solid circle (●) P143, asterisk (∗) P144, and double circle (◎) P145. The horizontal lines represent the mean double conductivity ratios of P142, fitted as follows: on graph (a), the value 1×10^{-5} was subtracted from the measured value for serial numbers above 10; for graph (b), the values 2×10^{-5} and 1×10^{-5} were subtracted from the measured value for serial numbers 21 to 26 and 27 to 31, respectively.

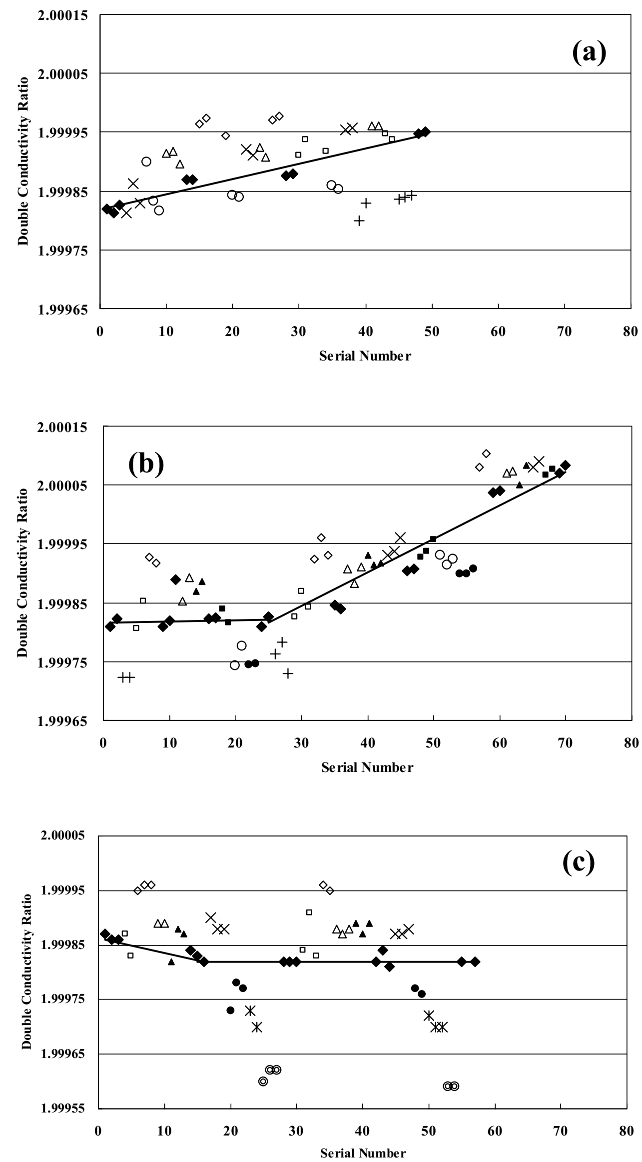

Fig. 2. Results of comparison experiments by WHOI (a) in 2002 (b) in 2003 and (c) in 2005. Plus (+) represents data for P133, square (□) P135, diamond (◇) P136, triangle (△) P137, solid triangle (▲) P138, cross (×) P139, circle (○) P140, solid square (■) P141, solid diamond (◆) P142 (reference), solid circle (●) P143, asterisk (∗) P144 and double circle (◎) P145. Drifts were calculated by fitting data from P142 to the equation obtained by the least square method (solid lines). Correction was made to compensate for the drift.

2.3 Results of the cross-laboratory comparison experiment

Figure 1 shows the results of the comparison experiments conducted at JAMSTEC. The horizontal lines represent the mean double conductivity ratios of P142. Fitting was done as follows: on graph (a), the value 1×10^{-5} was subtracted from the measured value for serial numbers above 10; for graph (b), the values 2×10^{-5} and 1×10^{-5} were subtracted from the measured value for se-

Table 1(a). Results of cross-laboratory comparison experiment in 2002.

	Slabel	JAMSTEC				WHOI			
		Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$	Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$
P133	34.9945	34.9944	0.4	5	–0.1	34.9944	0.2	5	–0.1
P134									
P135	34.9969	34.9967	0.2	7	–0.1	34.9967	0.2	5	–0.1
P136	34.9984	34.9980	0.6	5	–0.4	34.9982	0.3	5	–0.2
P137	34.9980	34.9971	0.3	7	–1.0	34.9973	0.3	7	–0.5
P138	34.9976								
P139	34.9972	34.9973	0.3	7	0.1	34.9969	0.5	7	–0.3
P140	34.9965	34.9959	0.2	7	–0.6	34.9961	0.8	7	–0.4
P141	34.9972								
P142	34.9965	34.9964	0.1	17	–0.1	34.9964	0.2	9	0.0
P143	34.9957								

Table 1(b). Results of cross-laboratory comparison experiment in 2003.

	Slabel	JAMSTEC				WHOI			
		Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$	Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$
P133	34.9945	34.9948	0.7	5	0.4	34.9949	0.6	5	0.4
P134									
P135	34.9969	34.9969	0.2	5	0.0	34.9967	0.5	5	–0.1
P136	34.9984	34.9983	0.3	7	0.1	34.9983	0.4	7	–0.2
P137	34.9980	34.9971	0.5	7	–0.9	34.9973	0.4	7	–0.8
P138	34.9976	34.9978	0.2	7	0.2	34.9973	0.4	7	–0.4
P139	34.9972	34.9974	0.4	5	0.2	34.9973	0.4	5	0.1
P140	34.9965					34.9955	0.4	5	–0.9
P141	34.9972	34.9966	0.4	5	–0.7	34.9967	0.2	7	–0.5
P142	34.9965	34.9962	0.1	12	0.0	34.9965	0.1	16	0.0
P143	34.9957	34.9953	0.2	5	–0.4	34.9948	0.3	5	–0.9

Table 1(c). Results of cross-laboratory comparison experiment in 2005.

	Slabel	JAMSTEC				WHOI			
		Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$	Mean	Sigma $\times 10^{-3}$	N	Smeas-Slab $\times 10^{-3}$
P135	34.9969	34.9971	0.3	4	0.2	34.9969	0.8	5	0.1
P136	34.9984	34.9987	0.2	4	0.3	34.9988	0.3	5	0.4
P137	34.9980	34.9972	0.3	4	–0.8	34.9975	0.1	5	–0.5
P138	34.9976	34.9974	0.5	6	–0.2	34.9973	0.7	6	–0.3
P139	34.9972	34.9975	0.2	7	0.3	34.9976	0.2	6	0.4
P140	34.9965	34.9961	0.0	1	–0.4				
P141	34.9972	34.9966	0.3	4	–0.6				
P142	34.9965	34.9965	0.2	15	0.0	34.9965	0.2	14	0.0
P143	34.9957	34.9954	0.1	2	–0.3	34.9953	0.4	5	–0.4
P144	34.9949	34.9941	0.4	3	–0.8	34.9942	0.2	5	–0.7
P145	34.9925	34.9923	0.2	9	–0.2	34.9922	0.3	5	–0.3

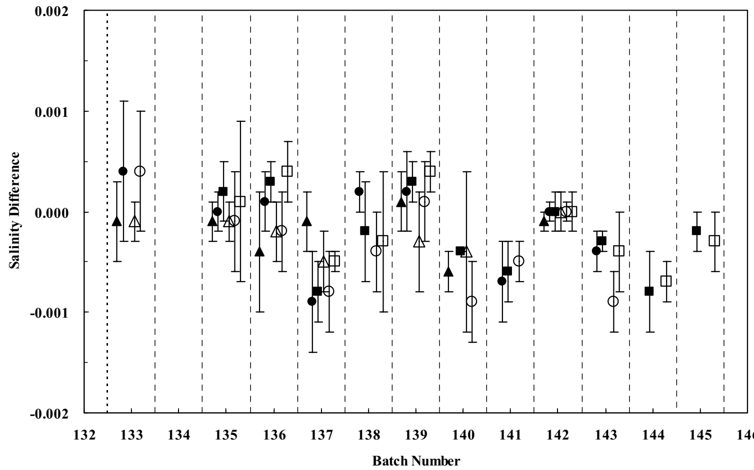

Fig. 3. Results of cross-laboratory comparison experiments. X-axis shows batch number of SSW and Y-axis shows difference between measured and label-derived salinity of P142. Solid triangle (▲), solid circle (●) and solid square (■) represent differences obtained by the experiment at JAMSTEC in 2002, 2003 and 2005, respectively. Open triangle (△), open circle (○) and open square (□) represent differences obtained by the experiment at WHOI in 2002, 2003 and 2005, respectively.

rial numbers 21 to 26 and 27 to 31, respectively. This is rather arbitrary but we decide on the step-like correction considering mainly the history of the "STNBY" value of the salinometer. Figure 2 shows the results of the comparison experiments conducted at WHOI. Drifts were calculated by fitting data from P142 to the equation obtained by the least square method (solid lines). Correction was made to compensate for the drift. The results after correction are summarized in Table 1 and Fig. 3. The standard deviation (1σ) ranged from 0.1×10^{-3} to 0.8×10^{-3} in salinity. This is consistent with recent studies such as that of Takatsuki *et al.* (1991), except for old batches such as P133, P136, and P138. The standard deviation of P140 in 2002 at WHOI, 0.8×10^{-3}, was quite large considering the age of this batch, though the source of imprecision is not clear. The batch-to-batch differences with respect to SSW batch P142 ($\Delta S = S_{measure} - S_{label}$) ranged from -1.0×10^{-3} to 0.4×10^{-3}. Batch-to-batch differences obtained at WHOI and JAMSTEC were consistent with each other (see Fig. 3).

2.4 *Comparison experiment at JAMSTEC, 2004*

A comparison experiment was performed at JAMSTEC in 2004. Measurements were conducted by the same method and under the same conditions as the comparison experiments described above, using the same SSW batch (P142) as reference. The results are summarized in Table 2. The standard deviations of P135, P138, and P143 were noticeably larger than the others, though the source of imprecision is not clear. ΔS changed abruptly for P137 and P143. The abrupt change for P143 may be attributable to inaccurate measurement.

Table 2. Results of SSW comparison experiment conducted at JAMSTEC in 2004.

	Slabel	Mean	Sigma $\times10^{-3}$	N	Smeas-Slab $\times10^{-3}$
P135	34.9969	34.9973	0.8	5	0.4
P136	34.9984	34.9990	0.4	4	0.5
P137	34.9980	34.9979	0.2	5	–0.2
P138	34.9976	34.9970	0.9	7	–0.7
P139	34.9972	34.9974	0.1	7	0.1
P140	34.9965				
P141	34.9972				
P142	34.9965	34.9965	0.3	16	0.0
P143	34.9957	34.9946	0.8	5	–1.1
P144	34.9949	34.9941	0.3	5	–0.8
P145	34.9925				

3. The Latest Batch-to-batch Difference Table

3.1 *Updated Batch-to-batch differences from P132 to P145*

Using these results and the outcomes of previously published comparison experiments for the period 1991–2001 (Table 3), we updated the table proposed by Kawano *et al.* (2001) and expanded the batch-to-batch difference table of Aoyama *et al.* (2002) to include batches up to P145. In order to combine recent comparison experiments, an adjustment value was added to the result of each comparison experiment as described in Kawano *et al.* (2001). The adjustment value was calculated to minimize the sum

Table 3. Comparison experiments used for updating batch-to-batch difference table.

Institution	Experiment date	Reference batch	Target batch (number of measured ampoules)
JAMSTEC[1)]	May 1999	P132(18)	P123(6), P124(5), P128(12), P133(7), P134(7), P135(6)
JAMSTEC[2)]	June 2000	P132(11)	P123(3), P133(3), P134(3), P135(3), P136(3), P137(3)
JAMSTEC[2)]	April 2001	P137(13)	P133(3), P134(3), P135(3), P136(3), P138(30)
JAMSTEC[2)]	June 2001	P139(13)	P133(3), P134(4), P135(3), P136(5), P137(5), P138(5), P140(30)
JAMSTEC[3)]	May 2002	P142(17)	P133(5), P135(7), P136(5), P137(7), P139(7), P140(7)
WHOI[3)]	July 2002	P142(9)	P133(5), P135(5), P136(5), P137(7), P139(7), P140(7)
JAMSTEC[3)]	July 2003	P142(12)	P133(5), P135(5), P136(7), P137(7), P138(7), P139(5), P141(5), P143(5)
WHOI[3)]	August 2003	P142(16)	P133(5), P135(5), P136(7), P137(7), P138(7), P139(5), P140(5), P141(7), P143(5)
JAMSTEC	July 2004	P142(16)	P135(5), P136(4), P137(5), P138(7), P139(7), P143(5), P144(5)
JAMSTEC	March 2005	P142(15)	P135(4), P136(4), P137(4), P138(6), P139(7), P140(1), P141(4), P143(2), P144(3), P145(9)

[1)]Kawano *et al*. (2000).
[2)]Kawano *et al*. (2001).
[3)]Cross-laboratry comparison experiment in this study.

of the squares of the differences between overlapping batches of SSW. Table 4 shows the updated batch-to-batch difference table for batches P133 to P145. We used the same adjustment value for the experiment in 1999 (JAMSTEC'99 in the table) as Kawano *et al.* (2001), since it was calculated to combine the results with the batch-to-batch difference table by Aoyama *et al.* (2002). Thereafter, the adjustment value was assigned according to the method described above. Following the method of Aoyama *et al.* (2002), the batch-to-batch difference for each batch was the median of the differences obtained for that batch. Ideally, the adjustment value would be equal to the batch-to-batch difference of the SSW that was used as a reference. In 1999 and 2000, batch P132 was used as a reference. As shown in Table 4, the adjustment value and the batch-to-batch difference were nearly equal except for batch P137. For example, the batch-to-batch difference of P142 was -1.1×10^{-3}, and the adjustment values after 2002 ranged from -1.0×10^{-3} to -1.1×10^{-3}. This result indicates that the method for combining the results of the earlier experiments and more recent experiments (described above) is adequate.

3.2 *Filling the blanks in the batch-to-batch difference table*

The batch-to-batch difference table of Aoyama *et al.* (2002) and the updated batch-to-batch difference table (above) do not have values for P113, P115, P117, P125, P126, P130, and P131. As described in the Introduction, Culkin and Ridout (1998) and Bacon *et al.* (2000) published batch comparison results including P115, P125, P126, P130, and P131 as examples of the aging effect of SSW. After detailed examination of their experiments, we offer another interpretation of their comparison data.

Culkin and Ridout (1998) performed comparison experiments for batches P120 to P129 against newly prepared KCl defined solution. Their results were tabulated in order of batch number. Originally, salinity differences were interpreted as temporal salinity changes because the samples were measured against the defined solution. However, Kawano *et al.* (2005) pointed out that the KCl solution may not actually be a valid standard for salinity measurements, even if it is prepared in exact accordance with the currently defined procedure, because the electrical conductivity ratio of the KCl solution depends on the lot of the reagent. If the experiments with two or more batches of SSW measured on the same day are chosen from the results of Culkin and Ridout (1998), the data can be treated as a comparison experiment for SSW.

Bacon *et al.* (2000) analyzed salinity data collected during seven cruises between 1991 and 1997 and examined how salinity of SSW batches P115, P116, P120, P121,

Table 4. Updated batch-to-batch differences and adjustment values provided by each comparison experiment.

Batch	Date	K15	Salinity	JAMSTEC '99	JAMSTEC '00	JAMSTEC '01	JAMSTEC '01	JAMSTEC '02	WHOI '02	JAMSTEC '03	WHOI '03	JAMSTEC '04	JAMSTEC '05	WHOI '05	Median	Standard deviation
	Adjustment value			*−1.6*	*−1.6*	*−1.4*	*−1.1*	*−1.0*	*−1.1*	*−1.1*	*−1.0*	*−1.1*	*−1.0*	*−1.0*		
P132	9-Apr-97	0.99993	34.9973	−1.6	−1.7										−1.7	0.1
P133	11-Nov-97	0.99986	34.9945	−1.3	−1.3	−0.8	−0.7	−1.1	−1.2	−0.7	−0.6				−1.0	0.3
P134	4-Jun-98	0.99989	34.9957	−1.0	−1.1	−1.4	−0.6								−1.1	0.3
P135	9-Feb-99	0.99992	34.9969	−1.5	−1.1	−1.3	−1.3	−1.1	−1.2	−1.1	−1.1	−0.7	−0.8	−0.9	−1.1	0.2
P136	16-Apr-99	0.99996	34.9984		−0.7	−1.1	−1.2	−1.4	−1.3	−1.0	−1.2	−0.6	−0.7	−0.6	−1.1	0.3
P137	9-Dec-99	0.99995	34.9980		−1.6	−1.4	−2.0	−2.0	−1.6	−2.0	−1.8	−1.3	−1.8	−1.5	−1.7	0.3
P138	7-Feb-00	0.99994	34.9977			−1.5	−1.8			−0.9	−1.4	−1.8	−1.2	−1.3	−1.4	0.3
P139	10-Nov-00	0.99993	34.9973				−1.1	−0.9	−1.4	−0.9	−0.9	−1.0	−0.7	−0.6	−0.9	0.2
P140	10-Nov-00	0.99991	34.9965				−1.6	−1.6	−1.5		−1.9		−1.4		−1.6	0.2
P141	12-Jun-02	0.99993	34.9973							−1.8	−1.5		−1.6		−1.6	0.2
P142	14-Nov-01	0.99991	34.9965					−1.1	−1.1	−1.1	−1.0	−1.1	−1.0	−1.0	−1.1	0.1
P143	26-Feb-03	0.99989	34.9957							−1.5	−1.9	−2.2	−1.3	−1.4	−1.5	0.4
P144	23-Sep-03	0.99987	34.9949									−1.9	−1.8	−1.7	−1.8	0.1
P145	15-Jul-04	0.99981	34.9926										−1.2	−1.3	−1.3	0.1

P124, P125, P128, P130, P131, and P132 changed by assuming that there was no batch-to-batch difference in SSW (i.e., the salinity of SSW immediately after preparation [label value] was correct, and changes over time were due to aging). The changes in salinity shown in table 2 of Bacon *et al.* (2000) were comparable to the batch-to-batch differences of both the current study and Aoyama *et al.* (2002). Therefore, we have re-examined their results by considering each of their batches as a separate SSW comparison experiment similar to the current study. For example, the results from the cruise of the RRS Discovery are described in section b. of Bacon *et al.* (2000): Two SSW sets (P115 + P120 and P115 + P116 + P120) were compared. Using P120 as a reference, P115 from the first set was saltier by 2.9×10^{-3} than the label value, and P115 and P116 from the second set were saltier by 1.7×10^{-3} and 1.3×10^{-3}, respectively. Some methods are again needed to combine these results with the table of Aoyama *et al.* (2002) and the updated table reported here. In the case of P132 to P145, the comparison experiments were designed to be suitable to create the table. However, we have to choose the somewhat arbitrary "key batch method" of Aoyama *et al.* (2002) in this case because there are few overlaps of common batches of SSW with the previous experiment. Table 5 compares the results of Culkin and Ridout (1998) (identified by date of experiment), Bacon *et al.* (2000) (identified by section), and the current study. We used P120 as a first key for conjunction between the result of Culkin and Ridout (1998) and that of Bacon *et al.* (2000), viz., columns number 1, 2, 3, 10, 11, 12, and 14. P122 was used as the second key for matching the results in columns number 2, 3, 4, and 5. The third key was P125 for matching the results in columns 6, 7, 13, 14, and 15. P127 and P130 were then used for the results in columns 7, 8, and 9, and columns 15, 16, and 17, respectively. The batch-to-batch difference for each batch was defined as the median of the differences for that batch from each experiment. Finally, adjustment values were calculated to minimize sum of the squares of the differences between overlapping batches of SSW. Overlapping results for five batches (P120, P122, P125, P127, and P130) were compared. Figure 4 shows the batch-to-batch differences proposed in Subsection 3.1 (above) and those obtained from the data of Culkin and Ridout (1998) and Bacon *et al.* (2000). Since the batch-to-batch differences of overlapping batches were in close agreement, we adopted the batch-to-batch differences for non-overlapping batches P115, P125, P126, P130, and P131 to fill the blanks in the table proposed in Subsection 3.1.

3.3 The latest batch-to-batch difference table

The batch-to-batch difference table proposed in the current study is presented in Table 6, starting with batch

Table 5. Comparison of batch-to-batch differences and adjustments proposed by Culkin and Ridout (1998), Bacon *et al*. (2000), and the current study.

	Culkin and Ridout (1998)									Bacon *et al.* (2000)								Combined table	This study
Batch	1/19/93	5/8/93	1/13/94	7/27/94	11/22/94	2/7/95	7/18/95	11/21/95	3/19/96	b-1	b-2	c	d	e	f	g-1	g-2		
Adjustment value	*0.4*	*0.4*	*0.4*	*0.0*	*0.4*	*1.1*	*0.7*	*0.3*	*–0.1*	*0.0*	*0.0*	*0.0*	*0.3*	*0.3*	*0.4*	*–0.4*	*–0.2*	*–1.4*	
P115										2.9	1.7	3.3	2.2					1.2	
P116											1.3	2.7						0.6	0.1
P117																			
P118																			–0.2
P119																			–1.3
P120	0.0	0.0	0.0							0.0	0.0	0.0		0.0				–1.4	–2.2
P121	0.4	0.4	0.8									1.1						–0.8	–0.9
P122		0.4	0.4	0.4	0.4													–1.0	–0.9
P123			0.0		0.4	1.1												–1.0	–0.6
P124				0.4	0.4	1.1							1.0					–0.7	–0.7
P125					0.4	0.3	0.3						0.3	0.3	0.3			–1.1	
P126						0.7	0.7	0.3										–0.7	
P127							0.7	0.7	0.7									–0.7	–0.5
P128								0.7	0.7							1.2	1.5	–0.5	0.1
P129									0.3									–1.1	–0.9
P130															0.4	0.4	0.4	–1.0	
P131																0.4	–0.1	–1.3	
P132																–0.4	–0.2	–1.7	–1.7
Column No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*

Table 6. The latest batch-to-batch differences proposed in this study.

Batch	Date	K15	Salinity	Batch to batch difference ($\times 10^{-3}$)	
				Mantyla's standard	New reference
P91	10-May-80	1.00007	35.0027	–1.0	0.3
P92	29-Oct-81	0.99988	34.9953	–1.5	–0.2
P93	31-Oct-81	0.99990	34.9961	–0.4	0.9
P94	18-Nov-81	0.99992	34.9969	–0.2	1.1
P95	8-Mar-83	0.99997	34.9988	0.9	2.2
P96	3-Mar-83	1.00006	35.0023	1.2	2.5
P97	3-Mar-83	1.00002	35.0008	0.8	2.1
P98	3-Mar-83	0.99993	34.9973	0.8	2.1
P99	27-Jul-84	0.99997	34.9988	–0.4	0.9
P100	29-Nov-84	1.00003	35.0012	–0.3	1.0
P101	4-Jun-85	1.00002	35.0008	0.5	1.8
P102	29-Nov-84	1.00001	35.0004	0.2	1.5
P103	11-Oct-85	0.99987	34.9949	–0.3	1.0
P104	21-Feb-86	0.99994	34.9977	–0.2	1.1
P105	21-Feb-86	0.99988	34.9953	0.8	2.1
P106	8-Jun-87	0.99989	34.9957	–0.8	0.5
P107	11-Nov-87	0.99991	34.9965	–0.2	1.1
P108	7-Apr-88	0.99980	34.9922	0.4	1.7
P109	7-Apr-88	0.99976	34.9906	0.9	2.2
P110	20-Jul-88	0.99999	34.9996	0.6	1.9
P111	7-Feb-89	0.99982	34.9930	0.8	2.1
P112	4-Jul-89	0.99984	34.9937	0.6	1.9
P113					
P114	30-Jul-90	0.99986	34.9945	0.7	2.0
P115	6-Feb-91	0.99986	34.9945	1.2	2.5*
P116	10-Jul-91	0.99981	34.9926	0.1	1.4
P117					
P118	12-Nov-91	0.99994	34.9977	–0.2	1.1
P119	28-Feb-92	0.99990	34.9961	–1.3	0.0
P120	6-Apr-92	0.99985	34.9941	–2.2	–0.9
P121	8-Sep-92	0.99985	34.9941	–0.9	0.4

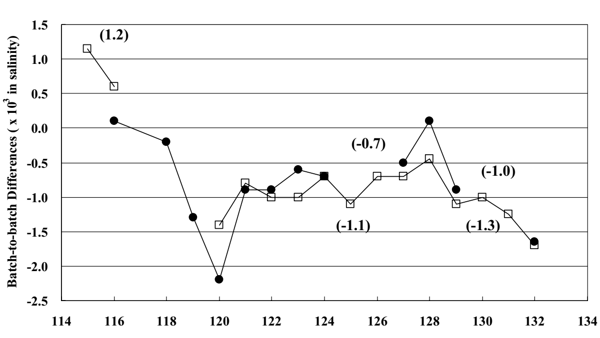

Fig. 4. Batch-to-batch differences in this study (●) and those obtained from Culkin and Ridout (1998) and Bacon *et al.* (2000) (□). X-axis represents SSW batch number and Y-axis represents batch-to-batch differences. Batch-to-batch differences in salinity are multiplied by 10^3. Values in parentheses are the batch-to-batch differences adopted to fill the blanks.

P91 (the first batch whose salinity was defined by electrical conductivity ratio). The batch-to-batch differences of P115, P125, P126 and after P130 are the product of the current study. Consistency among batches has been quite improved for recent batches of SSW. A standard deviation of batch-to-batch differences of P130 to P145 ranged from -0.9×10^{-3} to -1.8×10^{-3} with average -1.3×10^{-3} and standard deviation 0.3×10^{-3}. This standard deviation is about half of the value reported by Takatsuki *et al.* (1991) and almost equal to the resolution of the salinometer (0.2×10^{-3}). Note that the average, -1.3×10^{-3}, was the relative value referred to the average of batch-to-batch differences from P91 to P102 (Mantyla's standard). This reference was employed in order to ensure consistency with previous tables by Mantyla (1980, 1987, 1994), Takatsuki *et al.* (1991) and Aoyama *et al.* (2002).

Uncertainty in the proposed batch-to-batch differences depends on possible inconsistency in the conduc-

Table 6. (continued).

Batch	Date	K15	Salinity	Batch to batch difference ($\times 10^{-3}$)	
				Mantyla's standard	New reference
P122	21-Jan-93	0.99991	34.9965	–0.9	0.4
P123	10-Jun-93	0.99994	34.9977	–0.6	0.7
P124	18-Jan-94	0.99990	34.9961	–0.7	0.6
P125	1-Aug-94	0.99982	34.9930	–1.1	0.2*
P126	29-Nov-94	0.99987	34.9949	–0.7	0.6*
P127	14-Feb-95	0.99990	34.9961	–0.5	0.8
P128	18-Jul-95	0.99986	34.9945	0.1	1.4
P129	22-Nov-95	0.99996	34.9984	–0.9	0.4
P130	21-Mar-96	0.99997	34.9988	–1.0	0.3*
P131	10-Oct-96	0.99986	34.9945	–1.3	0.1*
P132	9-Apr-97	0.99993	34.9973	–1.7	–0.4*
P133	11-Nov-97	0.99986	34.9945	–1.0	0.3*
P134	4-Jun-98	0.99989	34.9957	–1.1	0.3*
P135	9-Feb-99	0.99992	34.9969	–1.1	0.2*
P136	16-Apr-99	0.99996	34.9984	–1.1	0.3*
P137	9-Dec-99	0.99995	34.9980	–1.7	–0.4*
P138	7-Feb-00	0.99994	34.9977	–1.4	–0.1*
P139	10-Nov-00	0.99993	34.9973	–0.9	0.4*
P140	10-Nov-00	0.99991	34.9965	–1.6	–0.3*
P141	12-Jun-02	0.99993	34.9973	–1.6	–0.3*
P142	14-Nov-01	0.99991	34.9965	–1.1	0.2*
P143	26-Feb-03	0.99989	34.9957	–1.5	–0.2*
P144	23-Sep-03	0.99987	34.9949	–1.8	–0.5*
P145	15-Jul-04	0.99981	34.9925	–1.3	0.1*

*Offsets proposed in this study.

tivity of PSS78 solution pointed out by Kawano *et al.* (2005), aging pointed out by Culkin and Ridout (1998) and Bacon *et al.* (2000), and within-batch difference and measurement precision of each experiment pointed out by Aoyama *et al.* (2002). The small standard deviation of batch-to-batch differences of P130 to P145 shows that these uncertainty factors were all satisfactorily small. Kawano *et al.* (2005) pointed out that purity on the label of the reagent supplied by Merck (called "Suprapur") changed recently from "99.5+" to "99.999". When we consider this kind of improvement in purity of reagents and improved consistency among batches, it might be better to refer to the average of the recent batches instead of the average of older batches. Such change of reference shifts batch-to-batch differences parallel to those in the previous tables and the result is shown in Table 6 as "new reference" together with previous reference mentioned above. Figure 5 shows batch-to-batch differences with reference to the average of those from P130 to P145. It is clear that the consistency among batches has improved since the 1980s. Batch-to-batch difference will not significantly change differences among salinities measured with reference to SSW batches in this decade. But when we calculate differences between salinity measured with reference to SSW batches before 1990 and that measured with reference to SSW batches after 1995, there is a possibility of obtaining unrealistic salinity increases.

4. Application to the WOCE Sections

4.1 *Comparison along WHP repeat lines in the Indian Ocean*

Fleurant and Molinari (1998) compared bottle salinities from WHP repeat lines I7N, I1W, I8N, and I8S. Observations of those lines were made twice in 1995 by NOAA ship Malcolm Baldridge and R/V Knorr of WHOI. The positions of both observations were compared, and stations within 0.1° were considered matched stations. Mean bottle salinity differences at depths of 2,000 m and below were calculated for matched stations. The authors reported that salinity values fell well within the WOCE data quality standard requirement (2×10^{-3} in accuracy for salinity); however, salinity differences may have arisen from the use of different SSW batches. Table 7 summarizes their comparisons as well as the results after applying the batch-to-batch differences table; by applying the

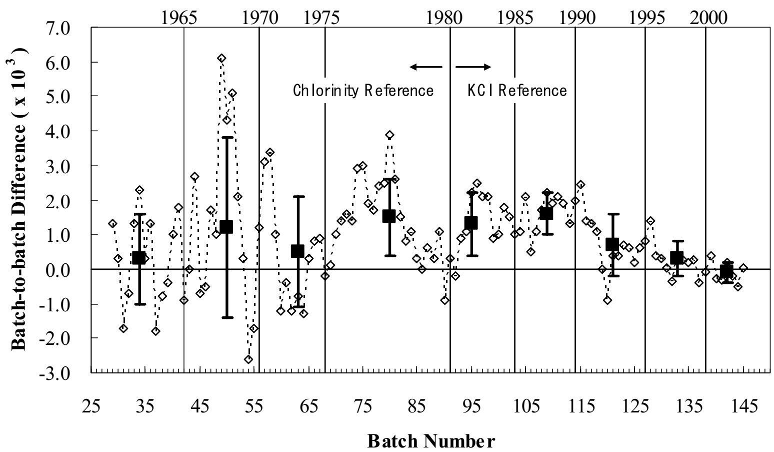

Fig. 5. Batch-to-batch differences with reference to the recent batches. X-axis is batch number of SSW and Y-axis is batch-to-batch difference in salinity. Open diamonds (◇) show batch-to-batch difference of each batch and squares show an average over every 5 years. Error bar represents a standard deviation.

table, all mean bottle salinity differences were decreased by 0.4×10^{-3} to 0.6×10^{-3}.

4.2 *Comparison at crossover points of the WHP onetime section in the Indian Ocean*

Salinity differences were examined at the WHP crossover points in the Indian Ocean. The proposed batch-to-batch differences in Table 6 were applied to data obtained from the website of the CLIVAR/CARBON Hydrographic Data Office (CCHDO, http://whpo.ucsd.edu/). Salinity comparisons were made at the crossings of onetime lines except for I06SB (because the SSW batch number is not shown in the cruise report). We defined a crossover point as a pair of stations located within a 0.05° square. As in Aoyama *et al.* (2002), bottle salinity was interpolated on the θ surfaces ranging from 0.25°C to 1.6°C in 0.05° increments. Crossover points where the salinity was measured against the same batch of SSW were excluded. Fifteen available crossover points was found, but the crossover point at I05W-663 and I05P-33 was excluded because the salinity difference was high compared to other crossover points of I05W and I05P, with no obvious explanation. Table 8 lists the WHP line IDs and station numbers, SSW batch numbers, batch-to-batch differences, and salinity differences (uncorrected and corrected) for the crossover points. Absolute values of uncorrected salinity differences at 14 crossover points ranged from 0.1×10^{-3} to 2.0×10^{-3} with an average of 1.2×10^{-3}. After applying the table, absolute values of salinity differences (ranging from 0.2×10^{-3} to 3.5×10^{-3} with an average of 1.5×10^{-3}) were slightly larger at seven crossover points, unchanged at five, and slightly lower at two. When we considered salinity differences at 14 crossover points in the Indian Ocean, 39 crossover points in the Pacific Ocean (Aoyama *et al.*, 2002), and 52 crossover points in the Atlantic Ocean (Gouretski and Jancke, 1998), altogether, the differences between the histograms in Fig. 6 (uncorrected vs. corrected) are not as large as those reproduced in Aoyama *et al.* (2002), and the corrected values are statistically reasonable if we assume that the salinity differences at crossover points are due to random error.

4.3 *Application to the WHP onetime line in the North Pacific*

WHP onetime line P1, located mainly along 47°N from coast to coast across the sub-Arctic Pacific, was observed in 1985. The line was revisited in 1999 and observed at the same stations by four different expeditions (hereafter referred to collectively as P1R): P1H (corresponding to the segment from 145.6°E to 146.6°E), P1W (145.5°E to 166°W), P1C (166°W to 145.6°W), and P1E (145.6°W to 123.5°W). Data for P1 were obtained from the CCHDO website, and data for P1R were published by Uchida *et al.* (2002). Figure 7 shows differences in CTD salinity between P1 and P1R below 2,000 m. All the results fell within the WOCE data quality standard requirement of 1×10^{-3} for salinity. We therefore consider differences $<3 \times 10^{-3}$ to be insignificant. Deep salinity increased by more then 3×10^{-3} in almost the entire area (Fig. 7 upper panel). Such a great change is difficult to explain in light of the distribution of deep salinity in the North Pacific reported by Reid (1997). We also see an obvious mismatch at 145.6°W, the boundary between P1C and P1E. The SSW batch used for P1 (P96, batch-to-batch difference = 1.2×10^{-3}) was different from those of the four cruises for P1R (P1H and P1C: P135, -1.1×10^{-3}; P1W: P133, -1.0×10^{-3}; P1E: P134, $-1.1 \times$

Table 7. Application of batch-to-batch difference table to WHP repeat lines in the Indian Ocean.

Line ID	Ship	Batch #	Batch-to-batch difference	Depth range	# of points used	Mean salinity difference	
						Uncorrected	Corrected
			$\times 10^{-3}$			$\times 10^{-3}$	$\times 10^{-3}$
I7N	Malcolm Baldridge	P125	−1.1	>3,000 m	641	0.9	0.3
	Knorr	P126	−0.7				
I1W	Malcolm Baldridge	P125	−1.1	>3,000 m	328	1	0.5−0.6
	Knorr	P123, P124	−0.6, −0.7				
I8S	Malcolm Baldridge	P125	−1.1	>2,500 m	163	3	2.6
	Knorr	P124	−0.7				
I8N	Malcolm Baldridge	P125	−1.1	>2,000 m	773	1	0.6
	Knorr	P126	−0.7				

Table 8. Application of batch-to-batch difference of SSW to the Indian WOCE crossover point.

Point A			Point B			Salinity difference (A–B)	
Line ID and Station	Batch #	Batch diff.[1)] $\times 10^{-3}$	Line ID and Station	Batch #	Batch diff.[1)] $\times 10^{-3}$	Uncorrected $\times 10^{-3}$	Corrected $\times 10^{-3}$
I05W-624	P126	−0.7	I05P-14	P97	0.8	1.3	−0.2
I05W-638	P126	−0.7	I05P-22	P97	0.8	0.5	−1.0
I05W-646	P126	−0.7	I05P-26	P97	0.8	0.7	−0.8
I05W-652	P126	−0.7	I05P-27	P97	0.8	−2.0	−3.5
I05W-663[2)]	P126	−0.7	I05P-33	P97	0.8	−14.2	−15.7
I05W-664	P126	−0.7	I05P-34	P97	0.8	−1.0	−2.5
I02E-1078	P128	0.1	I10-1075	P126	−0.7	0.6	1.4
I02E-1138	P128	0.1	I08N-322	P126	−0.7	2.0	2.8
I01E-965	P124	−0.7	I08N-283	P126	−0.7	0.6	0.6
I01W-929	P124	−0.7	I07N-782	P126	−0.7	0.9	0.9
I05E-406	P126	−0.7	I08S-11	P124	−0.7	1.8	1.8
I01E-966	P124	−0.7	I05E-284	P126	−0.7	1.7	1.7
I01W-861	P124	−0.7	I07N-808	P126	−0.7	1.8	1.8
I04-622	P126	−0.7	I05P-13	P97	0.8	−0.1	−1.6
I04-626	P126	−0.7	I05P-15	P97	0.8	1.8	0.3
					Mean[3)]	1.2	1.5
					STD[3)]	0.6	1.0

[1)]Batch-to-batch difference.
[2)]Data is not used for analysis.
[3)]Mean and standarad deviation are shown for absolute value for both corrected and uncorrected salinity differences.

10^{-3}). As noted by Fukasawa *et al.* (2004), salinity mismatches and large changes in salinity along separate segments in deep water disappear when the batch-to-batch difference table is applied.

WHP Sections P17C and P17N were observed in 1991 and 1993, respectively. P17C (northern segment) and P17N were revisited in 2001 (hereafter, P17R). Data for P17C and P17N were obtained from the CCHDO

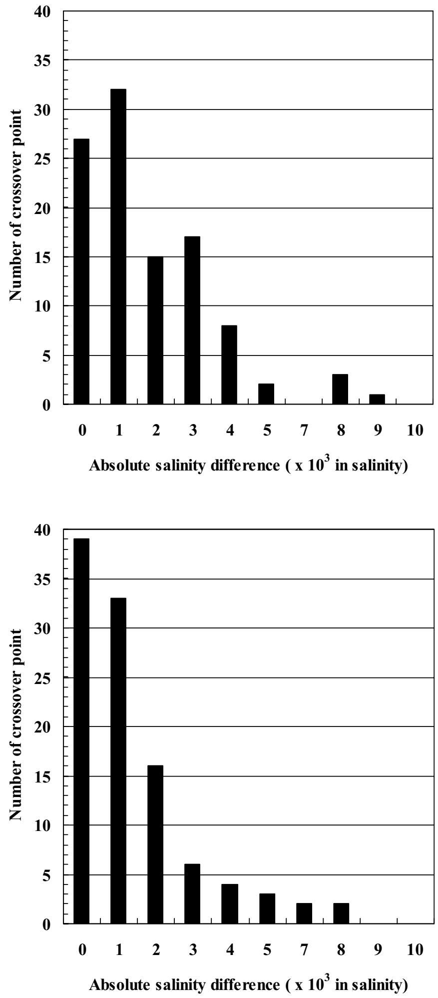

Fig. 6. Application of SSW batch-to-batch differences to 105 crossover points in the Indian, Pacific and Atlantic Oceans. Upper panel shows a histogram of absolute uncorrected salinity differences and lower panel shows that of absolute corrected salinity difference.

website, and data for P17R were published by Uchida and Fukasawa (2004). Data quality for all observations was well controlled. SSW batches P114 (batch-to-batch difference = 0.7×10^{-3}), P122 (-0.9×10^{-3}), and P139 (-0.9×10^{-3}) were used as references for P17C, P17N, and P17R, respectively. The line from 30°N to 34°N corresponds to the northern segment of P17C, and the line from 34.5°N to 54°N corresponds to P17N. Differences in most of the deep ocean area (Fig. 8) were not significant (less than $+/-3 \times 10^{-3}$ in salinity), but we found a distinct increase in salinity at around 34°N to 34.5°N, even though the P17N and P17C lines were continuous and the interval between observations were too short to expect changes in deep oceanic structure. When the batch-to-batch difference table was applied (see Fig. 8, lower panel), the sharp change in salinity was reduced to a reasonable level. Salinity differences north of 34.5°N did not change because the batch-to-batch differences for P122 and P139 were the same.

5. Summary

SSW batch comparison experiments were conducted independently at WHOI and JAMSTEC at about the same time using the same procedure. Batch-to-batch differences obtained at both institutions agreed well. Using these results and the outcomes of published comparison experiments, we updated the table proposed by Kawano *et al.* (2001) and expanded the batch-to-batch difference table of Aoyama *et al.* (2002) to include batches up to P145. Batch-to-batch differences of recent batches P130 to P145 ranged from -0.9×10^{-3} to -1.9×10^{-3} with reference to Mantyla's standard (the average of batch-to-batch differences from P91 to P102). Batch-to-batch differences from P29 to P145 with reference to the recent batches and the average of them over every 5 years since 1960 together with standard deviation were also presented. They revealed that inconsistency among batches has been improved since the 1980s. In particular, the standard deviation was 0.3×10^{-3} in this decade, which is about half the value reported by Takatsuki *et al.* (1991) and almost equal to the modern measurement precision (0.2×10^{-3}) and within-batch difference ($<0.3 \times 10^{-3}$) reported by Aoyama *et al.* (2002).

When the batch-to-batch difference table was applied to 14 crossover points on the WHP onetime section in the Indian Ocean, the average absolute salinity difference below the layer $\theta < 1.6$ increased slightly (from 1.2×10^{-3} to 1.5×10^{-3}). However, application of batch-to-batch differences to the combined results from crossover points in the Indian, Pacific, and Atlantic Oceans produced statistically acceptable salinity differences when we assume that salinity differences at crossover points are attributable to random error.

The batch-to-batch difference table was also applied to WHP sections P1, P17, I1, I7, I8, P1, and P17. Sections I1 and I8 were visited twice by different research vessels in the same year, and P1 and P17 were revisited about 10 years after original observations were made during the WOCE period. In all cases, unrealistically large salinity changes in space and time were corrected by applying the table. In the Indian Ocean (sections I1, I7, and I8), the mean salinity difference in deep water decreased by about 0.5×10^{-3}. In the North Pacific, section P1 salinity below 3,000 m appeared to increase by about 3×10^{-3} in the past 10 years, and section P17 showed a substantial change at the boundary between P17C and P17N. However, the differences were reduced to statistically acceptable levels when batch-to-batch differences were applied. As shown in the case of the crossover points in

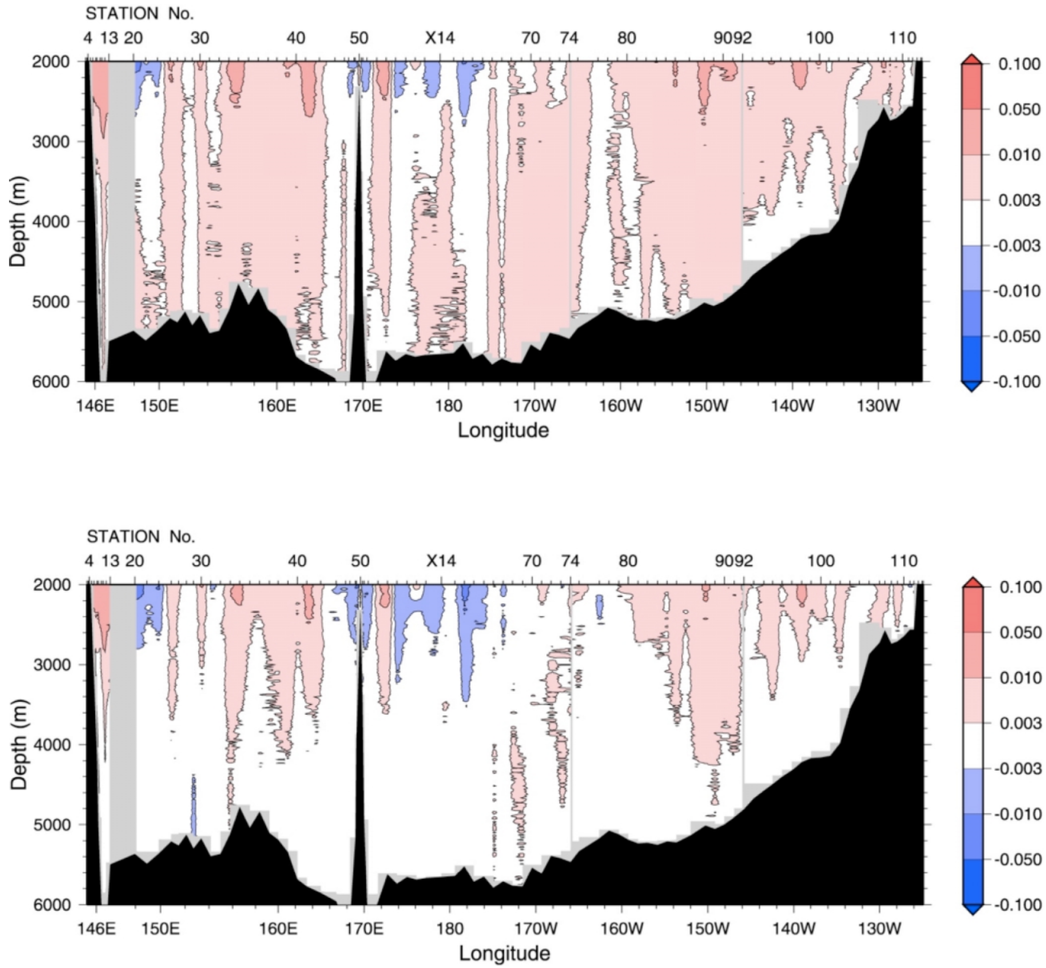

Fig. 7. Vertical section of salinity differences between P1 and P1R. Salinity values derive from PSS78, and contour intervals are variable. Differences between -3×10^{-3} and 3×10^{-3} (white) are considered insignificant. The apparent increase of salinity in deep water and the mismatch around the boundary between P1C and P1E seen in uncorrected salinity differences (upper panel) become more reasonable after the batch-to-batch difference table is applied (lower panel).

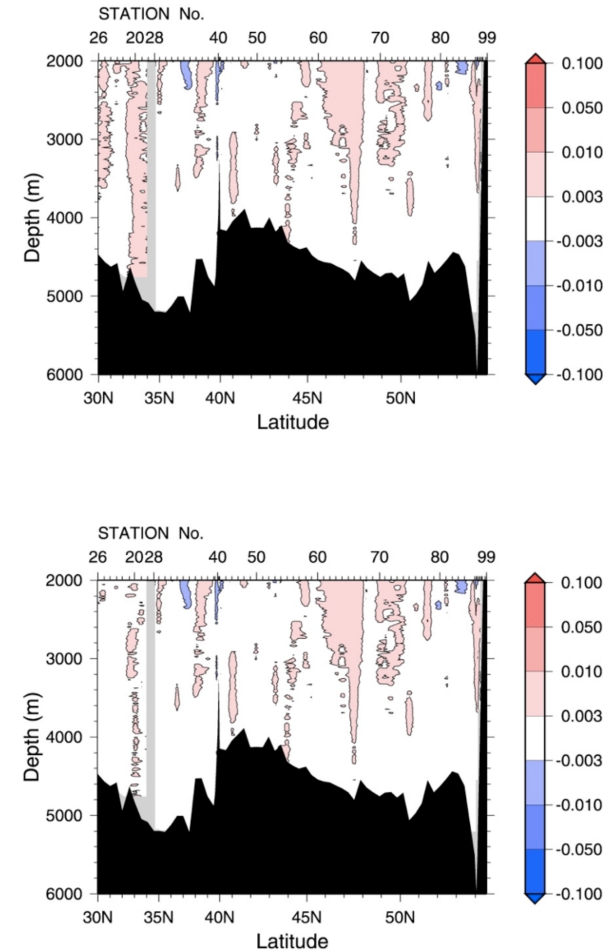

Fig. 8. Vertical section of salinity differences between P17 and P17R. Salinity values derive from PSS78, and contour intervals are variable. Differences between -3×10^{-3} and 3×10^{-3} (white) are considered insignificant. The inconsistency seen around the boundary (34°N) between P17C and P17N in uncorrected salinity difference (upper panel) becomes unremarkable after the batch-to-batch difference table is applied (lower panel).

the Indian Ocean, applying the batch-to-batch difference table is not necessarily perfect. However, as shown in the application of P1, for example, it is worth trying, especially when focused on difference in salinity over decades.

The batch-to-batch difference table reported here, as well as the previous tables, was composed under the assumption that the change of SSW was not appreciable during the period that a series of SSW comparison experiments was conducted. This assumption is obviously not exact because salinity of SSW can change. However, the degree of change, as well as quantitative estimation of its time dependency, is not clear. Kawano *et al*. (2005) shows that inconsistency in the conductivity of PSS78 standard solution could be a source of an initial offset of SSW. This is just a probability, but if it is true, then to consider uncritically that the newest batch has no batch-to-batch difference can be inappropriate, and such estimations based on this consideration made by Bacon *et al*. (2000) and Culkin and Ridout (1998) could be imprecise. Further study, such as monitoring the salinity of SSW against PSS78 solution made from the very same high-quality reagent, is required to evaluate the "aging effect" and "initial offset" separately.

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