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Verification of the metrological Reliability of Standard Seawater Calibration

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Abstract – The calibration of standard seawater, the most relevant standard for worldwide Practical Salinity measurements, is based on a conductance ratio measurement of standard seawater and a defined KCl solution. The results of an interlaboratory comparison measurement of such conductance ratios are presented at various salinities (7, 19, 35) and temperatures (5, 15, 25, 35 °C). The comparison reveals a dependence of the conductance ratios on the measurement systems that is larger than the uncertainty currently assigned to Practical Salinity measurements. This jeopardizes long term continuity of Practical Salinity measurements, if the type of instrument currently used for standard seawater calibration should not be available one day. There is a need for a metrological network for oceanographic observables to put Practical Salinity measurements on a sustainable metrological ground.

I. INTRODUCTION

Nowadays, Practical Salinity is the worldwide agreed measure for the content of dissolved salt in seawater. It is an important input quantity for data bases of global observation systems which, in turn, provide data for oceanographic and climatological research.

According to the Practical Salinity Scale from 1978 (PSS-78) Practical Salinity is expressed as a polynomial of the conductance ratio between a seawater sample and a defined potassium chloride solution [1]. It must be noted that usually the term ‘conductivity ratio’ is habitually used in literature rather than ‘conductance ratio’, which is not correct. In first place, any salinometer measures a conductance value $G_m(\mathrm{SW})$ of a seawater sample in a measurement cell, whereas the value depends on cell design and on how the electrical measurement signal is evaluated. Seawater conductivity κ_{SW}, meaning the material property, which is often called ‘absolute conductivity’, can only be calculated from the measured conductance value, if the cell constant K_{cell} of the measurement cell is known:

$$\kappa_{\mathrm{SW}} = K_{\mathrm{cell}} G_{\mathrm{SW}} \quad . \tag{1}$$

To this end the cell constant must be measured using a conductivity measurement standard of known conductivity and solving eq. (1) for K_{cell}. The relative standard uncertainty of such standards is, in best case, around 0.02 % [3]. It can easily be shown from uncertainty progression [4] that the relative uncertainty of the cell constant is of the same magnitude, as is the conductivity uncertainty of a seawater sample measured with that cell. This uncertainty is too large to achieve uncertainties smaller than 0.002 in salinity, as demanded by WHPO [5]. For this reason, PSS-78 calculates Practical Salinity from the ratio between the conductance value $G_m(\mathrm{KCl})$ measured from the defined KCl solution and the conductance value measured from a seawater sample. It is assumed that K_{cell} and its uncertainty cancel by building the ratio, giving a smaller uncertainty for the conductance ratio

$$R = \frac{\kappa_{\mathrm{SW}}}{\kappa_{\mathrm{KCl}}} = \frac{K_{\mathrm{cell}} G_m(\mathrm{SW})}{K_{\mathrm{cell}} G_m(\mathrm{KCl})} \tag{2}$$

and, consequently, for Practical Salinity calculated thereof.

If K_{cell} cancels, indeed, the conductance and the conductivity ratio would obviously be the same. However, as will be demonstrated, the comparison measurement suggests that this assumption is erroneous, at least at the uncertainty level demanded for Practical Salinity.

In practice, seawater of a known conductance ratio, so called standard seawater (SSW), is used to calibrate and adjust Practical Salinity measurement devices. The PSS-78 background papers [2] describe in detail the preparation and measurement procedures to determine the conductance ratio of standard sweater. In this way, the PSS-78 background papers can be seen as the metrological reference for the traceability of Practical Salinity measurement results and SSW can be seen as the primary standard for Practical Salinity measurements. Typically, Practical Salinity results are traceable to the conductance ratio of so called IAPSO Standard Seawater (IAPSO SSW) that is produced by Ocean Scientific International Ltd. (OSIL). It should be noted that other seawater standards for are also used in the meanwhile [6].

The extraordinary production quality of IAPSO SSW has been verified several times [7]. Due to its history OSIL is without a doubt dedicated to serve oceanography beyond commercial interests. However, being a company, OSIL might unintentionally be forced to stop SSW production one day. This potential risk and the upcoming of new seawater standards raise the question for the inter-laboratory reproducibility of the conductance ratio of SSW that complies with the requirements of PSS-78. Up to know interlaboratory equivalence of conductance ratio measurements has been demonstrated only once between three laboratories during the establishment of PSS-78 [8]. Subsequent comparison measurements compared Practical Salinity results of seawater that were all traceable to IAPSO SSW [9, 10], but never again verified the capability of different labs to measure the conductance ratio of SSW, i.e. the conductance ratio between a seawater sample and a KCl solution.

After a description of the framework and the data evaluation procedure, results of an interlaboratory comparison measurement of conductance ratios between seawater and a KCl solution will be discussed, which were measured at various salinities and temperatures. The study aimed to investigate the equivalence of such conductance ratio measurements to quantify the reproducibility SSW calibration. The results will demonstrate that the interlaboratory reproducibility is about an order of magnitude worse that the uncertainty assigned to IAPSO SSW today.

II. FRAMEWORK AND DATA PROCESSING

A. Comparison measurement framework

The comparison measurement was conducted as pilot study CCQM-P142 by the Working Group on Electrochemical Analysis, under the umbrella of the Consultative Committee for the Amount of Substance of the International Bureau for Weights and Measures. It was initiated as part of the project “ENV 05 – Ocean” [11] within the European Metrology Research Program [12]. The national metrology institute of Germany, the Physikalisch-Technische Bundesanstalt (PTB), was the coordinating institute. 20 institutions participated, among which were 15 metrology institutes, 3 oceanographic laboratories, OSIL and a manufacturer of salinometers.

PTB had created a measurement protocol prior to the measurements. The protocol aimed to achieve best possible repeatability conditions for the measurements, since these are indispensable to realise small uncertainties for conductance ratios. Consequently, the participants should not open the bottles before they have started the measurements. They had to inspect the bottles for damage, leakage or visible contaminants in the solution. Each bottle had to be weighed, the results corrected for air buoyancy and they had to be compared with the masses noted by the coordinating lab to ensure bottle integrity. Before the measurements the samples had to be store in a dark and cool place. The institutes were instructed to keep the measurement conditions as stable as possible with respect to temperature, sample and measurement system. In particular, the time during which the samples had contact with ambient atmosphere had to be minimized to avoid evaporation or contamination. One and the same measurement system had to be used for all measurements and it was explicitly not allowed to recalibrate the cell constant between the KCl solution and the seawater measurements.

The nominal measurement temperature was 15°C, however, the institutes were also asked to measure at 5°C, 25°C and 35°C if possible. The participants had to report the actual measurement temperature and the corresponding conductances without compensating them to the set temperatures. Temperature compensation and calculation of the conductance ratio was performed by the coordinating lab for all results in the same way to ensure consistent data treatment.

Shipment to all the participating laboratories was performed at the same time and the measurements had to be conducted within a period of three month.

B. Samples of the comparison

The participants had to measure conductance values of three different seawater samples, having nominal conductivities around 1 S m^{-1}, 2.5 S m^{-1} and 4.3 S m^{-1} at 15°C, corresponding to salinities of around 7, 19 and 35 (g/kg-seawater). Additionally, the conductance of an aqueous KCl solution was measured. The KCl solutions had a mass fraction of around 32g/kg, similar, but not equivalent, to the mass fraction of the KCl solution defined in PSS-78 (conductivity around 4.3 S/m at 15°C).

The seawater samples have been prepared from surface seawater collected from the North Atlantic and stored in a 100 L PE barrel under cool and half-light conditions until sample preparation. To roughly adjust the samples to the respective nominal conductivities portions of the seawater have been diluted with ultrapure water and filled into 20 L barrels. The conductivity values corresponded to conductance ratios of 0.23, 0.58 and 1. The seawater of each barrel has been filtered with a 0.4 µm filter, homogenized, filled into 200 mL bottles of borosilicate glass and sealed with crimped rubber stoppers.

To prepare the KCl solution pure water has been filled into a 20 L barrel. An appropriate amount of KCl (Merck suprapur) has been weighed and dissolved to roughly achieve the target value. Then KCl or ultrapure water was added until the target conductivity was achieved. The solution was homogenized afterwards, filled into 200 mL borosilicate bottles and sealed with crimped rubber stoppers.

Homogeneity and stability of the samples were measured with a Guildline Autosal 8400B salinometer. The relative between bottle variations for all kinds of solutions were smaller than 10^{-5}. Furthermore, the conductance ratios were measured again at the end of the measurement period. The relative change of the conductance ratios for all kinds of solutions were smaller than 1.3×10^{-5}. Note that the stability results are also affected by the stability of the device. Hence, the actual solution stability is probably even better. Temperature drift of the bath was smaller than 1 K during that time.

C. Calculation of conductance ratios

To calculate comparable conductance ratios the following calculation steps have been performed.

Firstly, a pair of KCl solution and seawater conductances, which were both measured around a given set temperature at a given institute, had to be corrected to an average temperature $t_a = (t_{KCl}+t_{SW})/2$. t_{KCl} is the actual measurement temperature of the KCl solution and t_{SW} that of the seawater sample. Seawater conductance G_{SW} was linearly corrected according to

$$G_{SW}(t_a) = \frac{G_{SW}(t_{SW})}{1+\alpha_{SW(ta)}(t_{SW}-t_a)} \quad . \tag{3}$$

Here,

$$\alpha_{SW(ta)} = \left.\frac{\partial G_{SW}(t)/\partial t}{G_{SW}(t)}\right|_{ta} \tag{4}$$

is the relative, linear conductivity temperature coefficient of seawater at t_a. Note that $\alpha_{SW(ta)}$ is a solution property and does not depend on the specific cell used for the measurement. Therefore, $G_{SW}(t)$ has been calculated from a second order polynomial fit to the conductance results measured at institute 16 (results see Appendix B). The conductance of the KCl solution has been corrected to t_a in analogy. The difference between t_{KCl} and t_{SW} was typically about some mK, so that the uncertainty of $\alpha_{SW(ta)}$ was negligible. Then the conductance ratio was calculated, which was obviously referred to the t_a of this pair of seawater / KCl solution conductances. The procedure was repeated for all pairs of seawater and KCl solution conductances for all institutes. The coefficients of the polynomials for the different solutions used to calculate the relative linear temperature coefficients are given in Appendix A.

At this point all conductance ratios were still referred to different temperatures, spreading around the respective set temperatures t_{set} of 5°C, 15°C, 25°C and 35°C. Therefore, in a second step, the dependence of the conductance ratio on temperature has been determined for each solution type to correct the conductance ratios to the common set temperatures. To this end, a second order polynomial has been fit to the conductance ratios of institute 16 (given at temperatures around 5°C, 15°C, 25°C and 35°C). This polynomial was used to calculate the conductance ratios $R_i(t_{set})$ of all institutes i at the corresponding set temperatures. Then the medians of all conductance ratios belonging to a set temperature were calculated, giving four conductance medians (at 5°C, 15°C, 25°C and 35°C). In a second iteration step the polynomial was calculated again, now using the medians, which is more accurate than using the results of just one lab. The refined polynomial was then used to recalculate the conductance ratios $R_i(t_{set})$ for each institute i at all set temperatures. Note that deviations from the set temperature were typically up to some ten mK. The coefficients of the refined polynomial are also given in appendix A.

D. Uncertainty calculation

The comparison investigated the equivalence of conductance ratios. For the reasons mentioned in the introduction the uncertainty of the cell constant is not considered. Hence, only measurement precision of the measured conductance values and the systematic uncertainty of the temperature measurements contribute to the uncertainty of an individual conductance ratio. Note that uncertainties due to temperature instability is already included in the precision of the conductance values due their dependence on temperature. The uncertainties of the conductance ratios have been calculated straight forward according to GUM [4] from the input quantities (conductances and temperatures) and their uncertainties. It should be noted that the uncertainties of the coefficients of the temperature compentations have been calculated with a Monte Carlo simulation [13]. It should also be emphasized that the correlation of the temperature measurements for two conductances corresponding to the same institute and the same set temperature was considered in the uncertainty calculation assuming a correlation coefficient of one.

The comparison reference values (CRV) for each solution at each set temperatures and their uncertainties were calculated from the corresponding medians. The uncertainty of the median is given by [14]

$$u_M = \frac{1.9}{\sqrt{n-1}} Median(|R_i(t_{set}) - CRV(t_{set}|) \tag{5}$$

Due to the insignificant variance of the results of the homogeneity and stability measurements their contributions to the uncertainty of the CRVs have been neglected.

III. RESULTS AND DISCUSSION

E. Results

The individual conductance and temperature measurement results reported by the institutes are listed in appendix B. Fig. 1 shows the degrees of equivalence at 15 °C for the conductance ratio of the 4.3 S m^{-1} seawater (i.e. around Practical Salinity 35) and the KCl solution. The conductance ratios at 15 °C of these two solutions are of special interest, since they are close to the solutions used for standard seawater calibration and can serve to visualise the interlaboratory reproducibility of standard seawater calibration. The degree of equivalence is the difference between the conductance ratio calculated from the results of an individual laboratory and the corresponding CRV.

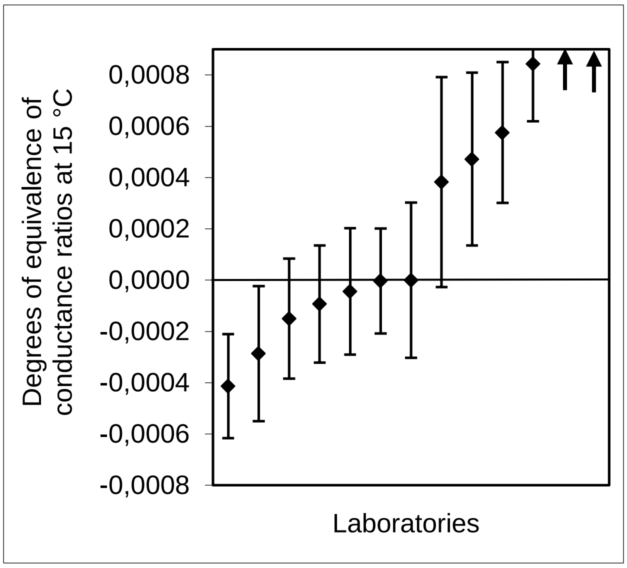

Fig. 1 Degrees of equivalence for the conductance ratios of seawater at Practical Salinity around 35 and a KCl solution around 32 g kg^{-1} at 15 °C, i.e. the PSS-78 reference point. The error bars indicate the uncertainty of the degrees of equivalence. The arrows indicate two results out of scale

The relative interlaboratory reproducibilities of conductance ratio measurements have been estimated from the expanded (U_M=2u_M)) uncertainties of the medians. The results are summarized in table 1.

Table 1 Relative interlaboratory reproducibility of conductance ratio measurements in terms of the expanded (k=2) uncertainty of the medians. Note that measurements at 21°C are all conducted with Autosal 8400B salinometers

	Salinity 7	Salinity 19	Salinity 35
5°C	0.126%	0.039%	0.021%
15°C	0.013%	0.019%	0.011%
21°C	0.007%	0.004%	0.001%
25°C	0.020%	0.011%	0.014%
35°C	0.248%	0.002%	0.026%

F. Discussion

The equivalences of the conductance ratios are significantly poorer than expected. It is commonly believed that the uncertainty of a conductance ratio measurement is smaller than that of an absolute conductivity measurement, since systematic uncertainties of the conductance measurement should cancel for the most part by building the ratio. This is basically the reason for using a conductance ratio to measure Practical Salinity. In contrast, the results of the study show uncertainties of the median that are not smaller than that of typical absolute conductivity measurements, which are in the order of 0.02 % [3]. Typically, in such comparison measurements there are outliers which decrease the quality of the comparison. However, one the one hand the medians are less sensitive to outliers compared to other evaluation methods like the weighted mean. Moreover, even if the evaluation is based only on results of experienced institutes that have proven good performance in past comparisons, the overall picture does not change significantly.

In past comparisons of Practical Salinity measurements virtually all results were referred to IAPSO SSW and the majority was measured with Guildline Autosal or Portasal instruments. There, the equivalence was in the order of 10^{-5} at salinities around 35 [9,10]. This is also reflected here by the results at 21°C and salinity 35, which were all measured with Autosal 8400B salinometers. However, even with those instruments, which are optimized for seawater, the spread increases with decreasing salinity.

Question is, how to explain the large spread seen in the other conductance ratio results. Conductance measurements of liquids always face the problem of electrode polarisation. Electrode polarisation describes charge transfer effects at the electrode solution interface. Even though the electrode design of conductance measurement cells aims at totally blocking electrodes, there is always some remaining current across the electrodes that is determined by the corresponding electrochemical reaction. Movement of the ions in the liquid to or away from the electrodes is determined by diffusion and migration in the electric field generated by the electrodes. Further, ions accumulate at the electrodes forming a diffusive double layer capacitance. These effects are affected by temperature, ion concentration, the kind of involved ions, design and material of the electrodes, the geometry of the measurement cell body, the electric conductivity and permittivity of the cell material and the surrounding medium used for temperature control and by the magnitude and shape of the electric signals applied to the electrodes (AC, DC, sin, pulse, etc.).

As a consequence, the actually measured conductance G_m(sol) is a superposition of the conductance G_{sol} of the solution in the cell, the actual value of interest, and some distorting side effects. Cell design and evaluation of the electric measurement signals, i.e. amplitudes and phases of the voltage and current signals, are usually optimised to minimise these distorting effects. However there always remains an unknown error ΔG_{sol}

$$G_m(\text{sol})=G_{\text{sol}}+\Delta G_{\text{sol}} \quad , \tag{6}$$

which makes it impossible to determine the exact value of G_{sol}. In first place calibration of a conductance cell with a measurement standard solution of known conductivity κ_{ref} aims to scale the actually measured conductance value $G_m(\text{ref})$ to the conductivity value of the standard by using eq. (1).

$$K_{\text{cell}} = \frac{\kappa_{\text{ref}}}{G_m(\text{ref})} = \frac{\kappa_{\text{ref}}}{G_{\text{ref}}+\Delta G_{\text{ref}}} \tag{7}$$

Hence, it also eliminates the systematic error ΔG_{ref} of the measurement setup, but of course the uncertainty of K_{cell} still includes the uncertainty of the measurement standard, which was likewise subject to the same distorting effects during its characterisation. By defining ‘conductace ratio’ as a new quantity of unit 1, this uncertainty contribution to the cell constant can indeed be omitted. However, the uncertainty of the conductance measurements (6) remains, so that (2) has to be transformed

$$R = \frac{G_{\text{SW}}+\Delta G_{\text{SW}}}{G_{\text{KCl}}+\Delta G_{\text{KCl}}} \tag{8}$$

As mentioned above, ΔG_{SW} and ΔG_{KCl} depend on the design of the measurement set-up. Even without a detailed uncertainty calculation of (8), which can be rather complex due to the effects determining ΔG_{SW} and ΔG_{KCl}, it is obvious that the uncertainties of conductance ratios are sensitive to differences in the measurement set-up and to differences in the solution. This is well reflected by the results of this comparison.

The optimum measurement point is the reference point of PSS-78 at Salinty 35 and 15°C (on IT-PS 68) at which R=1 (per definition). PSS-78 is empirically established on the cell design still integrated in an Autosal 8400B. Hence, it can be expected that these results are subject to low ΔG_{SW} and ΔG_{KCl} contributions and therefore they show low variability all over the salinity scale. The small decrease in the equivalence of the Autosal results with decreasing salinity is probably because of the measurement at 21°C and a slightly insufficient adjustment of the salinometers to temperatures deviating from 15°C.

For what concerns the results at other temperatures, it can be seen from table 1 that with only a few exceptions the uncertainties of the medians basically increase the more salinity and temperature deviate from 35 and 15°C, respectively. Even though most participants have used the same measurement principle (two electrode cells), the setups have varied in geometry and signal evaluation. Other measurement principles have also been used, one of which was another type of commercial salinometer. That type basically performs as well as the Autosal devices, if Practical Salinities are compared. However, it showed a significant deviation from the medians of this comparison. Hence, for the reasons mentioned it is assumed that the variability of the results in table 1 mainly reflects the variability in measurement setups used for the comparison.

IV. CONCLUSION

Calibration of the conductance ratio of standard seawater can be achieved with a degree of equivalence around 10^{-5} as long as high-end Autosal instruments are used, or if the corresponding conductance measurement cell and technique are used at least. However, if these instruments should not be available one day or other manufacturers of SSW become established, future calibrations of SSW could be biased with respect to today’s calibration. In this case all future Practical Salinity measurements could hardly be compared to preceding results, leading to a significant discontinuity in the data bases of global observation systems. For such reasons, measurement results must not depend on a specific instrument. Efforts have to be made to put Practical Salinity measurements on a solid, independent metrological ground. Therefore, a network of metrological institutes, oceanographic laboratories and industrial manufacturers of SSW and salinometers is needed to establish a metrological infrastructure for this important oceanographic observable.

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APPENDIX A: TEMPERTURE KOEFFICIENTS

Table 2.1 Coefficients $G(t)=at^2+bt+c$ used to calculate the linear conductivity temperature coefficients according to eq. (4) and based on results of Inst. 16.

coefficients	KCl-solution	SW 1 S m^{-1}	SW 2.5 S m^{-1}	SW 4.3 S m^{-1}
a / (S/°C^2)	2.02378E-04	7.53339E-05	1.79396E-04	2.92625E-04
b / (S/°C)	8.72683E-02	2.09528E-02	5.20513E-02	8.69523E-02
c	3.01081E+00	6.55992E-01	1.65747E+00	2.81693E+00

Table 3.2 Coefficients used for conductance ratio correction:
$R(t_{set}) = a(t_{set}^2 - t_a^2) + b(t_{set} - t_a) + R(t_a)$

	SW 1 Sm^{-1}	SW 2.5 Sm^{-1}	SW 4.3 Sm^{-1}
a / (1/°C^2)	-4.34586E-06	-5.32171E-06	-7.47316E-06
b / (1/°C)	6.26189E-04	1.18182E-03	1.67458E-03
$u(a)$	8.41E-08	3.56E-07	2.41E-07
$u(b)$	3.46E-06	1.47E-05	9.82E-06

APPENDIX B: REPORTED RESULTS

Table 4. Results for the aqueous KCl solution and the 1 S m^{-1} seawater

	KCl-aqu (32 g kg^{-1})				**SW 1 S m^{-1}**			
Inst. ID	t_{KCl} °C	$u(t_{\mathrm{KCl}})$ °C	$G(t_{\mathrm{KCl}})$ S	$u(G(t_{\mathrm{KCl}}))$ S	t_{SW} °C	$u(t_{\mathrm{SW}})$ °C	$G(t_{\mathrm{SW}})$ S	$u(G(t_{\mathrm{SW}}))$ S
1	15.005	0.0004	43.7072	0.0002	15.005	0.0004	9.8724	0.0001
	25.001	0.0004	53.2935	0.0002	25.001	0.0004	12.2732	0.0001
2	4.996	0.00076	0.0111	2.8E-07				
	14.999	0.0011	0.013761273	1.8E-07				
	25.001	0.0018	0.016779933	3.5E-07				
	35.000	0.0023	0.019762633	4.7E-07				
3	15.000	0.0032	0.0007	0.00000004	15.001	0.00128	0.0002	0.0000
	25.002	0.0010	0.0009	0.00000002	24.999	0.00273	0.0002	0.0000
4	4.996	0.0015	0.0004	0.00000001	5.007	0.0015	0.0001	0.0000
	15.006	0.0015	0.0005	0.00000002	15.004	0.0015	0.0001	0.0000
	25.006	0.0015	0.0006	0.00000001	25.003	0.0015	0.0001	0.0000
5	20.991	0.002	2.0185	0.00002100	20.991	0.002	0.4617	0.0000
6	15.006	0.0057	0.429266	0.000019	15.635	0.0063	0.098526	0.000014
	25.006	0.0059	0.523300	0.000035	25.042	0.0057	0.120779	0.000006
7	25.024	0.0058	0.524204	0.000034	25.026	0.0057	0.120729	0.000006
8	15.002	0.0031	0.019723	0.000004	15.001	0.0031	0.004596	0.000001
	25.001	0.0031	0.023818	0.000005	25.000	0.0031	0.005698	0.000001
9	23.994	0.0015	2.010300	0.000020	23.994	0.0015	0.462460	0.000020
10	15.032	0.044	0.010400	0.000001	15.037	0.044	0.0023770	0.0000002
11	15.000	0.005	33.1966	0.0018	15.000	0.005	7.5008	0.0008
	25.000	0.005	40.4642	0.0018	25.000	0.005	9.3261	0.0013
12	5.060	0.019	21.9293	0.0015	5.055	0.019	4.69655	0.00046
	14.912	0.02	27.6736	0.0040	14.920	0.02	6.0683	0.0011
	24.792	0.020	33.74965	0.00094	24.797	0.020	7.5470	0.0013
	34.659	0.020	40.04410	0.00094	34.666	0.020	9.1078	0.0013
13	15.003	0.006	13.65270	0.00040	14.998	0.006	3.0927	0.0007
	25.000	0.006	16.6306	0.0022	24.998	0.006	3.8425	0.0035
14	21.003	0.0009	1.009240	0.000013	21.004	0.0009	0.230875	0.000013
15	21.005	0.01	1.009220	0.000003	21.005	0.01	0.230900	0.000003
16	5.043	0.005	3.456823	0.000065	5.025	0.005	0.763358	0.000005
	15.013	0.005	4.364337	0.000060	15.024	0.005	0.987254	0.000015
	25.007	0.005	5.321951	0.000061	25.019	0.005	1.227904	0.000008
	35.043	0.005	6.316774	0.000099	35.046	0.005	1.482650	0.000011
17	15.000	0.003	377.5110	0.0220	15.000	0.003	85.3110	0.0010
	25.000	0.003	460.2630	0.0230	25.000	0.003	106.1140	0.0050
18	5.064	0.003	3.46430	0.00030	5.069	0.003	0.76354	0.00020
	14.999	0.003	4.36580	0.00030	15.001	0.003	0.98641	0.00020
	24.999	0.003	5.32485	0.00040	25.000	0.003	1.22715	0.00020
	35.042	0.003	6.32220	0.00050	35.042	0.003	1.48050	0.00020
19	15.003	0.004	4.3540	0.0005	15.001	0.004	0.9865	0.0005
	25.005	0.004	5.3020	0.0005	25.006	0.004	1.2260	0.0005

Table 5. Results for 2.5 S m^{-1} and 4.3 S m^{-1}seawater

	SW 2.5 S m^{-1}				**SW 4.3 S m^{-1}**			
Inst. ID	t_{KCl} °C	$u(t_{\mathrm{KCl}})$ °C	$G(t_{\mathrm{KCl}})$ S	$u(G(t_{\mathrm{KCl}}))$ S	t_{SW} °C	$u(t_{\mathrm{SW}})$ °C	$G(t_{\mathrm{SW}})$ S	$u(G(t_{\mathrm{SW}}))$ S
1	15.005	0.0004	24.7960	0.0001	15.005	0.0004	41.9011	0.0001
	25.001	0.0004	30.7387	0.0001	25.001	0.0004	51.8151	0.0001
2	5.001	0.00076	0.0062	7.4E-08				
	15.001	0.0011	0.007904535	2.1E-07				
	25.001	0.0018	0.009810033	2.6E-07				
	35.000	0.0023	0.011725667	3.7E-07				
3	14.998	0.00121	0.0004	0.0000	15.002	0.00233	0.0007	0.0000
	25.002	0.00072	0.0005	0.0000	24.999	0.0009	0.0008	0.0000
4	5.005	0.0015	0.0002	0.0000	4.997	0.0015	0.0004	0.0000
	14.999	0.0015	0.0003	0.0000	15.008	0.0015	0.0005	0.0000
	25.006	0.0015	0.0003	0.0000	25.004	0.0015	0.0006	0.0000
5	20.991	0.002	1.1573	0.0000	20.991	0.002	1.9526	0.0000
6	15.064	0.0063	0.243895	0.000019	15.009	0.00555	0.412098	0.000010
	25.047	0.0058	0.302162	0.000021	25.036	0.0055	0.509759	0.000013
7	25.052	0.006	0.302016	0.000030	25.027	0.0055	0.509876	0.000016
8	14.998	0.0031	0.01137875	0.000003	14.999	0.0031	0.019	0.000004
	25.002	0.0031	0.014025333	0.000003	25.001	0.0031	0.0231927	0.000005
9	23.995	0.0015	1.158210	0.000020	23.994	0.0015	1.952620	0.000020
10	15.038	0.044	0.005940	0.000001	15.040	0.044	0.009981	0.000001
11	15.000	0.005	18.8505	0.0053	15.000	0.005	31.8288	0.0022
	25.000	0.005	23.3352	0.0016	25.000	0.005	39.3525	0.0042
12	5.048	0.019	12.20715	0.00056	5.061	0.019	20.70195	0.0014
	14.906	0.02	15.7108	0.0017	14.913	0.02	26.54890	0.0029
	24.788	0.020	19.4810	0.0012	24.794	0.0195	32.83220	0.00083
	34.660	0.020	23.4528	0.0012	34.659	0.0195	39.43830	0.00083
13	15.001	0.006	7.7615	0.0003	14.994	0.006	13.0993	0.0012
	25.002	0.006	9.6173	0.0015	24.999	0.006	16.1876	0.0065
14	21.003	0.0009	0.578670	0.000013	21.004	0.0009	0.976275	0.000013
15	21.005	0.01	0.578690	0.000003	21.005	0.01	0.976245	0.000003
16	5.029	0.005	1.924211	0.000018	5.044	0.005	3.263752	0.000096
	15.029	0.005	2.478895	0.000017	15.020	0.005	4.186492	0.000033
	25.014	0.005	3.073112	0.000026	25.016	0.005	5.177660	0.000066
	35.047	0.005	3.701570	0.000062	35.051	0.005	6.223418	0.000073
17	15.000	0.003	214.2530	0.0090	15.000	0.003	362.0080	0.0070
	25.000	0.003	265.7670	0.0120	25.000	0.003	447.808	0.010
18	5.061	0.003	1.92320	0.00020	5.064	0.003	3.2687	0.0004
	15.000	0.003	2.47725	0.00030	15.000	0.003	4.1873	0.0004
	24.999	0.003	3.07290	0.00030	24.999	0.003	5.1805	0.0005
	35.043	0.003	3.70150	0.00040	35.042	0.003	6.2262	0.0005
19	14.999	0.004	2.4775	0.0005	15.001	0.004	4.1840	0.0005
	25.002	0.004	3.0690	0.0005	25.001	0.004	5.1690	0.0005