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The density of seawater as a function of salinity (5 to 70 $\mathrm{g\,kg^{-1}}$) and temperature (273.15 to 363.15 K)

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Abstract. New seawater density measurements were made as a function of temperature T=(273.15 to 363.15) K and salinity (5 to 70 $\mathrm{g\,kg^{-1}}$). The measurements (N=230) from T=273.15 to 313.15 K and Practical Salinity (S) from 0 to 40 were found to be in good agreement (σ=0.0036 $\mathrm{kg\,m^{-3}}$) with the equation of state of seawater (Millero and Poisson, 1981) made on samples with a known chlorinity (Cl). These results indicate that the Practical Salinities (S) are in agreement to within $\pm$0.003 $\mathrm{kg\,m^{-3}}$ with the values calculated from the Chlorinity, S_{Cl}=1.80655 Cl. The measurements from 298.15 to 363.15 were used to extend the equation of state to high temperatures and salinities. All the densities were made relative to pure water ($\rho-\rho^0$ where ρ^0 is the density for pure water) were fitted to equations of the form

$$(\rho - \rho^0)/(\mathrm{kg\,m^{-3}}) = AS_A + BS_A^{1.5} + CS_A^2$$

where A, B, and C are functions of temperature and S_A ($\mathrm{g\,kg^{-1}}$) is the absolute salinity, S_A=(35.16504/35) S $\mathrm{g\,kg^{-1}}$. The fitted results from S_A=0 to 50 $\mathrm{g\,kg^{-1}}$ and T=273.15 to 313.15 K (N=242) gave standard errors of 0.0037 $\mathrm{kg\,m^{-3}}$. The fitted results from 298.15 to 363.15 K (N=280) gave standard errors of 0.0063 $\mathrm{kg\,m^{-3}}$ and all the results (N=522) from 273.15 to 363.15 K gave standard errors of 0.0063 $\mathrm{kg\,m^{-3}}$. The earlier density measurements (Millero et al., 1976b; Poisson et al.,1980) used to determine the equation of state of seawater (Millero and Poisson, 1981) were combined to derive equations that are valid from 273.15 to 313.15 K and 273.15 to 363.15 K. The standard errors of these fits are respectively, 0.0038 $\mathrm{kg\,m^{-3}}$ (N=713) and 0.0063 $\mathrm{kg\,m^{-3}}$ (N=962). These new measurements expand the equation of state of seawater to a wider range of temperature (273.15 to 363.15) K and absolute salinity (0 to 70 $\mathrm{kg\,m^{-3}}$).

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1 Introduction

The original one atmosphere density measurements used to determine the equation of state of seawater (Millero and Poisson, 1981) were made on seawater of a known Chlorinity (Cl). The salinities of these samples were determined using the relationship

$$S_{\mathrm{Cl}} = 1.80655\mathrm{Cl} \tag{1}$$

This relationship may or may not be valid at the present time (Millero et al., 1976a). For example, the differences in the Practical Salinity (S) and Chlorinity salinity (S_{Cl}) calculated from Eq. (1) may vary by as much as 0.0055 (Fig. 1). This difference is equivalent to an error in density of $\pm$0.0041 $\mathrm{kg\,m^{-3}}$.

The present one atmosphere equation of state for seawater is limited to Practical Salinities from 0 to 40 and temperatures from 273.15 to 313.15 K. The equation was derived from the measurements of Millero et al. (1976b) and Poisson et al. (1980). A summary of these measurements are given in Table 1. The equation of state derived from the studies of Millero et al. (1976b) and Poisson et al. (1980) had a 1σ=0.0035 $\mathrm{kg\,m^{-3}}$ similar to the individual studies. Poisson and Gadhoumi (1993) have extended the range to higher Practical Salinities (S=50) from 288.15 to 303.15 K. They give equations that represent this data with standard errors close to those of the equation of state (Millero and Poisson, 1981). Measurements to a higher temperature are not available at the present time. As the physical chemical properties

Table 1. Summary of the 1 atm density measurements made on seawater.

Author	Number	Std Error (1σ)	Temperature	Salinity
Millero et al. (1976b)	122	0.0035 kg m^{-3}	273.15 to 313.15 K	1 to 40
Poisson et al. (1980)	344	0.0035 kg m^{-3}	273.45 to 303.15 K	5 to 41
Poisson and Gadhoumi (1993)	79	0.0064 kg m^{-3}	288.15 to 303.15 K	35 to 50
This Study	242	0.0037 kg m^{-3}	273.15 to 313.15 K	5 to 50
All Combined	713	(0.0036 kg m^{-3})		
This Study	280	0.0063 kg m^{-3}	273.15 to 363.15 K	4 to 70
All Combined	962	(0.0063 kg m^{-3})		

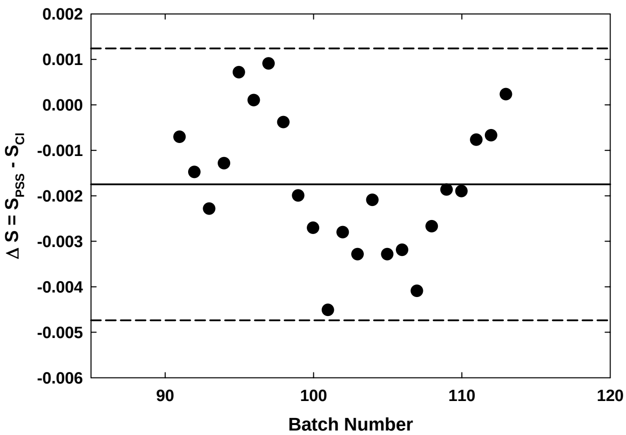

Fig. 1. The differences between the Practical Salinity (S_{PSS}) and the value calculated from the Chlorinity ($S_{\rm Cl}$=1.80655 Cl) for the last series of Standard Seawater where Chlorinity was measured (P91 to P113). The dotted lines are 2σ.

of seawater are known to higher temperatures (Millero and Pierrot, 2005; Feistel, 2008), there is a need for density measurements at higher temperatures and salinities.

In this paper, measurements of the density of seawater on the Practical Salinity Scale (S) have been made from 273.15 to 315.15 K and are compared to those calculated from the equation of state (Millero and Poisson, 1981). New measurements of the density of seawater to 363.15 K as a function of absolute salinity, S_A from 0 to 70 g kg^{-1} are also reported. This study is part of a work to extend the equation of state of seawater over a wider range of temperature and salinity (Feistel, 2008). The results will be useful in examining the use of ionic interaction models (Pierrot and Millero, 2000) to estimate the density over a wide range of temperature and ionic strength and in the future to examine the PVT properties of hydrothermal waters.

2 Experimental methods

The seawaters used in this study were Standard Seawater (S=35.00) and surface Gulf Stream seawater (S=36.10). Both waters have low nutrient concentrations and had densities that agreed at similar salinities to $\pm$0.003 kg m^{-3}. Solutions at low salinities were obtained by adding ion exchange water by weight and the high salinities by slowly evaporating the samples. No visible precipitation appeared during the sample preparation. The Practical Salinities were measured with an Autosal salinometer calibrated with Standard Seawater. The precision of the Practical Salinity is 0.0005 on a given sample. The absolute salinities of the evaporated samples were back calculated from the weight of the added water needed to dilute it to a salinity range that can be measured by conductivity and density at 298.15 K. The salinities of the evaporated samples are estimated to be accurate to $\pm$0.003 g kg^{-1}.

The densities were measured on a Paar 500 vibrating tube densimeter at a fixed temperature ($\pm$0.003 K) determined with a Platinum thermometer in the instrument. The densimeter is calibrated with deionized water (Millipore SuperQ) and dry air. The measurements made at high temperatures were made on degassed samples heated to 363.15 K to avoid bubble formation in the instrument. The measurements were then made from 263.15 to 298.15 K. Densities made on Standard Seawater were repeatable to 1σ=0.003 kg m^{-3} from 273.15 to 323.15 K and agree with values calculated from the equation of state (Millero and Poisson, 1981) to $\pm$0.0035 kg m^{-3} from 293.15 to 313.15 K. The measurements at temperature above 323.15 K have an estimated uncertainty of $\pm$0.006 kg m^{-3} based on repeat measurements of the same sample. All of the measurements were made relative to the density of water which is based on the equations of Kell (1975) adjusted to the 1990 temperature scale (Spieweck and Bettin, 1992). These are the densities that are embedded in the densimeter. The values of the relative densities ($\rho-\rho^0$) are not affected by densities used in the calibration of the system. The measured water values from 273.15 to 363.15 K agreed to the calculated values to

$\pm 0.002\,\mathrm{kg\,m^{-3}}$. Since the density of water (ρ^0) in the original equation of state of seawater is based on the less reliable water equations of Bigg (1967) and the values used in the instrument, all of our measurements are reported and compared to the equation of state of seawater (Millero and Poisson, 1981) in terms of the differences in the density of seawater and water ($\rho-\rho^0$) $\mathrm{kg\,m^{-3}}$.

A number of density measurements on deep waters in the Atlantic (Millero et al., 1976a; 1978), Indian (Poisson et al., 1981; Millero et al., 2008a), and Pacific oceans (Millero et al., 1978; 2009) and the Red (Poisson et al., 1981) and Baltic Seas (Millero and Kremling, 1976) are higher than the values determined from the equation of state (Millero and Poisson, 1981). This is attributed to the added salts to seawater from the dissolution of SiO_2 (s) and $CaCO_3$ (s) and the addition of CO_2 and nutrients from the mineralization of organic matter (Brewer and Bradshaw, 1975; Millero, 2000). Since the conductivity salinity does not respond to all the components in seawater, it is useful to examine the physical properties in terms of the absolute salinity (Millero et al., 2008b; Feistel, 2008). The absolute salinity ($\mathrm{g\,kg^{-1}}$) is defined (Millero et al., 2008b) by

$$S_A = S_R + \Delta S \tag{2}$$

where the Reference Salinity (S_R) is related to the Practical Salinity (S) by

$$S_R = (35.16504/35)\,\mathrm{g\,kg^{-1}} \times S \tag{3}$$

and ΔS is the increase due to added salts (Brewer and Bradshaw, 1975; Millero, 2000; Millero et al., 2008b). The values of ΔS can be estimated by determining the added Si, Ca, NO_3, PO_4 and TCO_2 to seawater (Millero et al., 2008a; 2009). It can also be estimated (Millero et al., 2009) from the differences between the measured densities and the values determined from the equations of state using the approximate equation

$$\Delta S_A/(\mathrm{g\,kg^{-1}}) = \Delta\rho(\mathrm{kg\,m^{-3}})/(0.752\,\mathrm{g\,kg^{-1}}) \tag{4}$$

where $\Delta\rho=\rho$ (measured) – ρ (calculated from the equation of state) at 25°C. For seawater with no added salts the values of S_A are equal to the Reference Salinity S_R and can be estimated from the Practical Salinity using Eq. (3).

3 Results and discussion

The densities made in this study are given in the Appendix Tables A1 and B1. Two sets of measurements were made from 273.15 to 313.15 K and S_A=4 to 50 $\mathrm{g\,kg^{-1}}$ and from 298.15 to 363.15 K and S_A=4 to 70 $\mathrm{g\,kg^{-1}}$. The first series of density measurements were made on Standard Seawater (S=35.00, Batch 90–115) and Gulf Stream seawater evaporated and diluted from S_A=4 to 42 $\mathrm{g\,kg^{-1}}$ and from 273.15 to 313.15 K. The measured densities (N=230) are compared

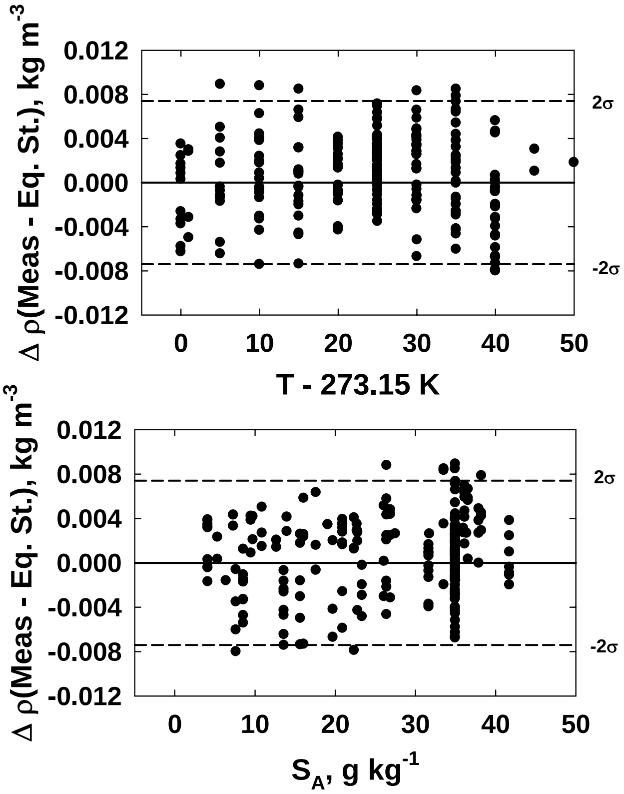

Fig. 2. The differences in the measured (N=230) densities ($\rho-\rho^0$, $\mathrm{kg\,m^{-3}}$) with those calculated from the equation of state (Millero and Poisson, 1981) as a function of temperature and salinity (σ=0.0036 $\mathrm{kg\,m^{-3}}$).

to the values calculated from the equation of state (Millero and Poisson, 1981) as a function of temperature and salinity in Fig. 2. The standard error between the measured and calculated values was 0.0036 $\mathrm{kg\,m^{-3}}$. This is similar to the errors in the repeat density measurements ($\pm 0.003\,\mathrm{kg\,m^{-3}}$) on the same sample and indicates that the salinities calculated by conductivity (S) and Chlorinity (S_{Cl}) are in agreement to $\pm 0.004\,\mathrm{g\,kg^{-1}}$. It should be pointed out that our measurements made at salinities above 40 are higher by as much as 0.064 $\mathrm{kg\,m^{-3}}$ with the measurements of Poisson and Gadhoumi (1993) at 288.15, 298.15 and 303.15 K.

The internal consistency of the measurements was examined by fitting the relative densities to an equation of the form

$$(\rho-\rho^0)/(\mathrm{kg\,m^{-3}}) = AS_A/(\mathrm{g\,kg^{-1}}) + B\{S_A/(\mathrm{g\,kg^{-1}})\}^{1.5} + C\{S_A/(\mathrm{g\,kg^{-1}})\}^2 \tag{5}$$

The variable A, B and C are functions of temperature (T/K)

$$A = a_0 + a_1(T/\mathrm{K}-273.15) + a_2(T/\mathrm{K}-273.15)^2 + a_3(T/\mathrm{K}-273.15)^3 + a_4(T/\mathrm{K}-273.15)^4 + a_5(T/\mathrm{K}-273.15)^5 \tag{5a}$$

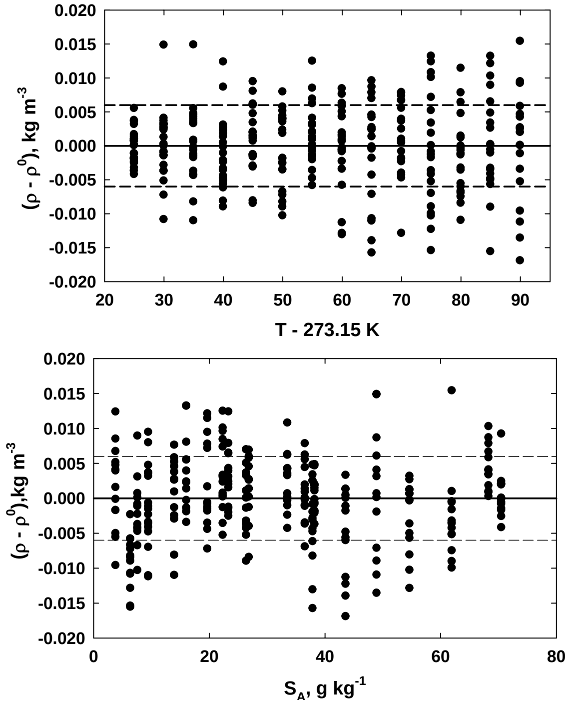

Fig. 3. The differences between the measured (N=522) and calculated densities ($\rho-\rho^0$, $\mathrm{kg\,m^{-3}}$) from 273.15 to 363.15 K and S_A from 5 to 70 $\mathrm{g\,kg^{-1}}$ as a function of temperature and salinity (σ=0.0063 $\mathrm{kg\,m^{-3}}$).

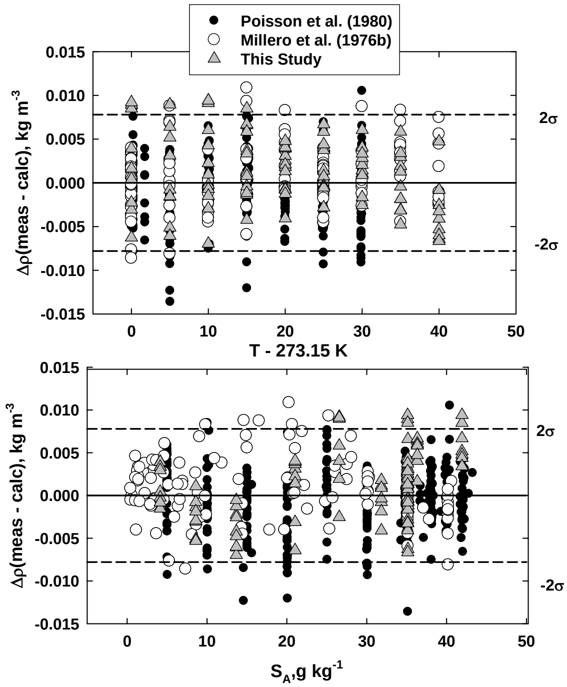

Fig. 4. The deviations between the measured (N=713) and calculated values from 273.15 to 313.15 K and S_A from 0 to 40 $\mathrm{g\,kg^{-1}}$ of Poisson et al. (1980). Millero et al. (1976b), and this study as a function of temperature and salinity (σ=0.0037 $\mathrm{kg\,m^{-3}}$).

$$B = b_0 + b_1(T/\mathrm{K} - 273.15) + b_2(T/\mathrm{K} - 273.15)^2 \quad (5b)$$

$$C = c_0 \quad (5c)$$

The parameters needed to fit the seawater measurements (N=242) from 273.15 to 313.15 K and S_A from 5 to 50 ($\mathrm{g\,kg^{-1}}$) are tabulated in Table 2 along with the standard error of the fit (σ=0.0037 $\mathrm{kg\,m^{-3}}$). This standard error of the 273.15 to 313.15 K fit is similar (Fig. 2) to the differences between our measurements and those calculated from the equation of state of seawater (Millero and Poisson, 1981). The parameters needed to fit the seawater measurements (N=280) from 298.15 to 363.15 K are also tabulated in Table 2 along with the standard error of the fit (σ=0.0063 $\mathrm{kg\,m^{-3}}$). All of the measurements from 273.15 to 363.15 K (N=522) have also been fitted to Eq. (5). The parameters for the fits are given in Table 2 along with the standard error of the fit (σ=0.0063 $\mathrm{kg\,m^{-3}}$). The differences between the measured and calculated densities from these fits are shown in Fig. 3. Most of the differences are within 2σ, where σ is the standard error of the fit. The errors appear to be larger at high temperatures, apparently due to difficulties in removing air from the samples. These measurements extend the equation of state to seawater as a function the absolute salinity S_A $\mathrm{g\,kg^{-1}}$ over a wide range of temperature and salinity.

The measurements made in this study from 273.15 to 315.15 K and 273.15 to 363.15 K have been fitted to Eq. (5) with all of the measurements used to determine the International Equation of state of seawater (Millero et al., 1976b; Poisson et al., 1980). The results of these fits (N=713 from 273.15 to 313.15 K and N=962 from 273.15 to 363.15 K) are tabulated in Table 3 along with the standard errors, respectively σ=0.0036 $\mathrm{kg\,m^{-3}}$ and σ=0.0063 $\mathrm{kg\,m^{-3}}$. The differences between the measured and calculated densities from 273.15 to 313.15 K and 273.15 to 363.15 K) are shown respectively, in Figs. 4 and 5. As with our other fits, most of the differences are within 2σ.

It should be pointed out that the earlier measurements (Millero et al., 1976b; Poisson et al., 1980) made on the 1968 temperature scale were converted to the 1990 temperature scale (Preston-Thomas, 1990). Changes in the temperature scale do not significantly affect the values of ($\rho-\rho^0$) which do not vary much with temperature. The results of this study can be used to determine the properties of seawater and most estuarine waters over a wide range of Absolute Salinity and temperature. These results will also be useful in extending the ionic interaction model for seawater (Pierrot and Millero, 2000) to 363.15 K. Future work on the density of seawater above 373.15 K at applied pressure are needed to extend the temperature range to the levels available for the thermochemical properties of seawater (Millero and Pierrot, 2005; Feistel, 2008).

Table 2. The coefficients for the densities measured in this study fitted to Eq. (2).

	273.15 to 313.15 K	298.15 to 363.15 K	273.15 to 363.15 K
S_A	8.246111E-01	8.055888E-01	8.174451E-01
$S_A(T/\mathrm{K}–273.15)$	−3.956103E-03	−2.588520E-03	−3.638577E-03
$S_A(T/\mathrm{K}–273.15)^2$	7.274549E-05	2.449074E-05	6.480811E-05
$S_A(T/\mathrm{K}–273.15)^3$	−8.239634E-07	3.908917E-08	−7.312404E-07
$S_A(T/\mathrm{K}–273.15)^4$	5.332909E-09	−1.795219E-09	5.330431E-09
$S_A(T/\mathrm{K}–273.15)^5$		8.617570E-12	−1.657628E-11
$S_A^{1.5}$	−6.006733E-03	−4.893389E-03	−5.481436E-03
$S_A^{1.5}(T/\mathrm{K}–273.15)$	7.970908E-05	2.132621E-05	3.486075E-05
$S_A^{1.5}(T/\mathrm{K}–273.15)^2$	−1.018797E-06	−1.907666E-07	−3.049727E-07
S_A^2	5.281399E-04	5.165275E-04	5.346196E-04
Number	242	280	522
Std.Err.Fit	0.0037 kg m^{-3}	0.0063 kg m^{-3}	0.0063 kg m^{-3}

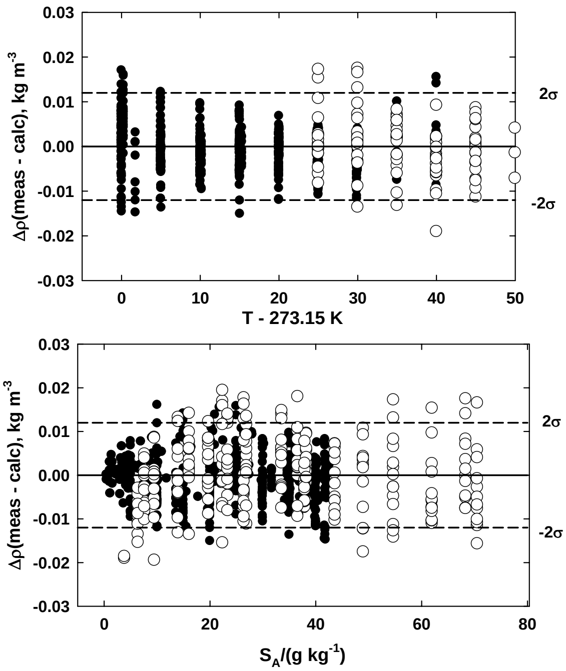

Fig. 5. The deviations between the measured (N=962) and calculated values from 273.15 to 363.15 K and S_A from 0 to 70 g kg^{-1} as a function of temperature and salinity (σ=0.0062 kg m^{-3}). The closed circles are from 273.15 to 313.15 K (Poisson et al., 1980; Millero et al., 1976b) and the open circles from this study are from 298.15 to 363.15 K.

Table 3. The coefficients for the densities measured in this study and literature data (Millero et al., 1976b; Poisson et al., 1980) fitted to Eq. (2).

	273.15 to 313.15 K	273.15 to 363.15 K
S_A	8.207423E-01	8.197247E-01
$S_A(T/\mathrm{K}–273.15)$	−4.090059E-03	−3.779454E-03
$S_A(T/\mathrm{K}–273.15)^2$	7.695554E-05	6.821795E-05
$S_A(T/\mathrm{K}–273.15)^3$	−8.284116E-07	−8.009571E-07
$S_A(T/\mathrm{K}–273.15)^4$	5.490137E-09	6.158885E-09
$S_A(T/\mathrm{K}–273.15)^5$		−2.001919E-11
$S_A^{1.5}$	−5.738085E-03	−5.808305E-03
$S_A^{1.5}(T/\mathrm{K}–273.15)$	1.044735E-04	5.354872E-05
$S_A^{1.5}(T/\mathrm{K}–273.15)^2$	−1.758636E-06	−4.714602E-07
S_A^2	4.840416E-04	5.249266E-04
Number	713	962
Std.Err.Fit	0.0036 kg m^{-3}	0.0063 kg m^{-3}

Table A1. The densities (kg m^{-3}) of seawater measured between 0 and 40°C.

t	S_A	Meas	t	S_A	Meas	t	S_A	Meas
°C	g kg^{-1}	kg m^{-3}	°C	g kg^{-1}	kg m^{-3}	°C	g kg^{-1}	kg m^{-3}
−0.002	31.837	25.587	10.004	35.157[a]	27.243	24.997	9.792	7.322
0.000	8.607	6.952	15.000	8.607	6.583	24.997	36.753	27.491
0.000	13.678	11.024	15.000	15.741	12.015	24.998	36.171	27.055
0.000	35.142	28.246	15.000	26.221	20.018	24.999	26.559	19.842
0.000	35.142	28.246	15.001	13.678	10.445	24.999	31.914	23.854
0.000	35.157[a]	28.251	15.001	21.037	16.064	24.999	35.168	26.298
0.000	35.157[a]	28.251	15.001	35.168	26.880	24.999	35.168	26.299
0.000	36.343	29.212	15.001	35.168	26.873	24.999	35.168	26.298
0.000	41.941	33.718	15.001	35.168	26.873	24.999	35.168	26.299
0.001	4.147	3.364	15.001	35.169	26.873	24.999	35.169	26.298
0.001	21.037	16.930	15.001	41.941	32.082	24.999	35.182	26.310
1.000	15.741	12.619	15.002	4.147	3.184	25.000	5.365	4.019
1.000	22.930	18.366	15.002	31.837	24.320	25.000	5.365	4.017
1.003	35.157[a]	28.134	15.002	35.157[a]	26.863	25.000	10.943	8.179
1.005	35.157[a]	28.140	15.002	36.343	27.781	25.000	15.741	11.756
4.999	41.941	33.064	15.003	35.132	26.854	25.000	17.706	13.219
5.000	10.943	8.651	15.003	35.142	26.854	25.000	17.706	13.226
5.000	15.741	12.420	15.003	35.142	26.854	25.000	22.930	17.124
5.000	31.837	25.083	15.004	35.157[a]	26.860	25.000	26.221	19.584
5.001	8.607	6.802	19.998	35.157[a]	26.550	25.000	26.221	19.589
5.001	13.678	10.790	19.998	35.157[a]	26.550	25.000	27.632	20.643
5.001	35.142	27.689	20.000	8.607	6.501	25.000	35.157[a]	26.290
5.001	35.142	27.689	20.000	10.943	8.263	25.000	35.157[a]	26.290
5.002	4.147	3.289	20.000	15.741	11.873	25.000	36.171	27.055
5.002	21.037	16.584	20.000	17.706	13.357	25.000	36.579	27.362
5.004	35.157[a]	27.711	20.000	22.930	17.291	25.001	4.147	3.111
5.005	35.157[a]	27.706	20.001	21.037	15.870	25.001	31.837	23.794
10.000	15.741	12.198	20.001	31.837	24.034	25.002	6.435	4.813
10.000	22.930	17.763	20.001	35.132	26.534	25.002	7.344	5.497
10.001	4.147	3.230	20.001	35.142	26.535	25.002	7.344	5.496
10.001	13.678	10.599	20.001	35.142	26.535	25.002	7.678	5.738
10.001	21.037	16.298	20.001	35.168	26.562	25.002	9.547	7.139
10.001	26.559	20.580	20.001	35.168	26.561	25.002	12.752	9.526
10.001	31.837	24.666	20.001	35.168	26.562	25.002	13.678	10.214
10.001	35.142	27.235	20.001	35.168	26.561	25.002	14.060	10.504
10.001	35.157[a]	27.240	20.001	35.169	26.561	25.002	19.183	14.325
10.001	35.168	27.257	20.002	4.147	3.144	25.002	19.183	14.325
10.001	35.168	27.252	20.002	13.678	10.319	25.002	21.037	15.710
10.001	35.168	27.257	20.002	36.343	27.455	25.002	22.843	17.059
10.001	35.168	27.252	20.002	41.941	31.710	25.002	23.478	17.529
10.001	35.169	27.252	20.003	35.157[a]	26.546	25.002	27.032	20.193
10.002	8.607	6.682	20.006	35.157[a]	26.550	25.002	31.832	23.791
10.002	41.941	32.530	24.995	22.487	16.791	25.002	35.132	26.274
10.003	35.157[a]	27.244	24.996	12.752	9.526	25.002	35.142	26.275
25.002	35.157[a]	26.296	30.005	68.654	51.393	40.000	35.157[a]	25.746
25.002	35.157[a]	26.286	30.006	9.547	7.078	40.000	35.157[a]	25.746
25.002	35.157[a]	26.296	30.006	70.871	53.089	40.001	21.037	15.378
25.002	35.157[a]	26.286	30.007	7.678	5.692	40.001	26.559	19.426
25.002	36.343	27.188	30.030	35.157[a]	26.069	40.001	36.343	26.625
25.002	41.941	31.401	30.030	35.157[a]	26.065	40.002	4.147	3.044

Table A1. Continued.

t	S_A	Meas	t	S_A	Meas	t	S_A	Meas
°C	$g\,kg^{-1}$	$kg\,m^{-3}$	°C	$g\,kg^{-1}$	$kg\,m^{-3}$	°C	$g\,kg^{-1}$	$kg\,m^{-3}$
25.003	19.821	14.800	34.997	35.157[a]	25.894	40.002	8.607	6.299
25.003	43.831	32.837	34.998	26.551	19.525	40.002	31.837	23.300
25.003	62.268	46.882	34.998	35.157	25.897	40.002	35.132	25.725
25.004	9.792	7.320	34.998	38.425	28.324	40.002	35.142	25.729
25.004	16.165	12.075	34.999	35.157[a]	25.892	40.002	35.142	25.729
25.004	22.843	17.060	34.999	35.157[a]	25.892	40.003	33.716	24.684
25.004	49.210	36.917	34.999	35.182	25.918	40.004	49.210	36.177
25.004	54.936	41.279	35.000	26.559	19.538	40.004	62.268	45.945
25.004	68.654	51.797	35.000	27.032	19.889	40.005	7.678	5.617
25.004	70.871	53.507	35.001	8.607	6.335	40.005	16.165	11.815
25.005	33.716	25.209	35.001	13.678	10.055	40.005	23.478	17.166
25.006	38.108	28.513	35.001	31.837	23.433	40.005	27.032	19.772
25.007	26.551	19.832	35.002	4.147	3.063	40.005	38.108	27.922
29.998	38.425	28.517	35.002	21.037	15.465	44.995	35.157[a]	25.637
29.999	35.182	26.094	35.002	35.132	25.875	44.995	35.157[a]	25.639
29.999	35.182	26.089	35.002	35.142	25.878	49.998	35.157[a]	25.564
30.001	8.607	6.381	35.002	35.142	25.878			
30.001	13.678	10.126	35.002	36.343	26.777			
30.001	21.037	15.576	35.002	36.753	27.082			
30.001	22.487	16.653	35.002	41.941	30.927			
30.001	26.559	19.675	35.003	22.487	16.536			
30.001	27.032	20.027	35.004	7.678	5.648			
30.001	35.157[a]	26.074	35.004	23.478	17.262			
30.001	35.157[a]	26.074	35.004	43.831	32.354			
30.001	36.343	26.963	35.005	9.547	7.027			
30.002	14.060	10.414	35.005	16.165	11.888			
30.002	31.837	23.598	35.005	19.821	14.569			
30.002	35.132	26.056	35.005	33.716	24.833			
30.002	35.142	26.059	35.005	38.108	28.084			
30.002	35.142	26.059	35.005	54.936	40.673			
30.003	4.147	3.084	35.005	62.268	46.202			
30.003	26.551	19.663	35.005	68.654	51.054			
30.003	43.831	32.573	35.005	70.871	52.739			
30.004	16.165	11.970	39.995	35.157[a]	25.747			
30.004	19.821	14.667	39.996	35.157[a]	25.748			
30.004	23.478	17.384	39.996	36.753	26.929			
30.005	33.716	25.005	39.998	38.425	28.161			
30.005	36.753	27.269	39.999	43.831	32.162			

[a] Measurements made on Standard Seawater (S_A=35.157 $g\,kg^{-1}$).

Table B1. The densities (kg m^{-3}) of seawater measured between 25 and 90°C.

t	S_A	Meas	t	S_A	Meas	t	S_A	Meas
°C	g kg^{-1}	kg m^{-3}	°C	g kg^{-1}	kg m^{-3}	°C	g kg^{-1}	kg m^{-3}
24.995	22.487	16.791	35.003	22.487	16.536	45.005	6.435	4.680
24.996	38.425	28.753	35.004	6.435	4.731	45.005	7.678	5.592
24.997	36.753	27.491	35.004	7.678	5.648	45.005	16.165	11.765
25.002	6.435	4.813	35.004	23.478	17.262	45.005	23.478	17.084
25.002	7.678	5.738	35.004	43.831	32.354	45.005	27.032	19.683
25.002	9.547	7.139	35.005	9.547	7.027	45.005	33.716	24.578
25.002	14.060	10.504	35.005	16.165	11.888	45.005	68.654	50.547
25.002	23.478	17.529	35.005	19.821	14.569	45.005	70.871	52.218
25.002	27.032	20.193	35.005	33.716	24.833	45.006	22.487	16.358
25.003	19.821	14.800	35.005	38.108	28.084	45.006	38.108	27.796
25.003	43.831	32.837	35.005	54.936	40.673	49.995	22.487	16.302
25.003	62.268	46.882	35.005	62.268	46.202	49.995	26.551	19.246
25.004	16.165	12.075	35.005	68.654	51.054	49.997	14.060	10.187
25.004	49.210	36.917	35.005	70.871	52.739	50.001	36.753	26.710
25.004	54.936	41.279	39.992	26.551	19.413	50.001	54.936	40.106
25.004	68.654	51.797	39.996	36.753	26.929	50.002	9.547	6.931
25.004	70.871	53.507	39.997	14.060	10.268	50.002	43.831	31.902
25.005	33.716	25.209	39.998	9.547	6.977	50.003	16.165	11.712
25.006	38.108	28.513	39.998	38.425	28.161	50.004	19.821	14.361
25.007	26.551	19.832	39.999	43.831	32.162	50.004	38.425	27.933
29.998	38.425	28.517	40.000	22.487	16.437	50.004	68.654	50.367
30.001	22.487	16.653	40.002	6.435	4.702	50.005	6.435	4.664
30.001	27.032	20.027	40.003	33.716	24.684	50.005	7.678	5.564
30.002	14.060	10.414	40.004	19.821	14.481	50.005	23.478	17.024
30.003	26.551	19.663	40.004	49.210	36.177	50.005	27.032	19.611
30.003	43.831	32.573	40.004	62.268	45.945	50.006	33.716	24.486
30.004	6.435	4.763	40.005	7.678	5.617	50.006	38.108	27.690
30.004	16.165	11.970	40.005	16.165	11.815	50.006	49.210	35.877
30.004	19.821	14.667	40.005	23.478	17.166	50.006	62.268	45.575
30.004	23.478	17.384	40.005	27.032	19.772	50.006	70.871	52.027
30.004	54.936	40.949	40.005	38.108	27.922	54.996	26.551	19.206
30.004	62.268	46.511	40.005	54.936	40.440	55.001	14.060	10.163
30.005	33.716	25.005	40.005	68.654	50.774	55.001	22.487	16.268
30.005	36.753	27.269	40.005	70.871	52.451	55.001	43.831	31.818
30.005	38.108	28.280	44.994	36.753	26.805	55.003	36.753	26.639
30.005	68.654	51.393	44.998	14.060	10.224	55.004	9.547	6.903
30.006	9.547	7.078	45.001	38.425	28.034	55.004	38.425	27.857
30.006	70.871	53.089	45.002	26.551	19.324	55.004	68.654	50.229
30.007	7.678	5.692	45.002	62.268	45.741	55.005	7.678	5.559
34.998	14.060	10.326	45.003	43.831	32.021	55.005	19.821	14.325
34.998	26.551	19.525	45.004	9.547	6.958	55.005	23.478	16.972
34.998	38.425	28.324	45.004	19.821	14.416	55.005	27.032	19.559
35.000	27.032	19.889	45.004	49.210	36.009	55.005	70.871	51.889
35.002	36.753	27.082	45.004	54.936	40.253	55.006	6.435	4.653
55.006	16.165	11.681	65.005	49.210	35.654	80.001	38.425	27.764
55.006	33.716	24.416	65.005	68.654	50.067	80.001	43.831	31.703
55.006	38.108	27.618	69.999	26.551	19.142	80.002	6.435	4.640
55.006	49.210	35.778	70.000	22.487	16.210	80.002	7.678	5.540
55.006	54.936	40.006	70.000	38.425	27.753	80.002	9.547	6.885
55.006	62.268	45.450	70.001	33.716	24.326	80.002	19.821	14.294
59.998	26.551	19.172	70.001	54.936	39.852	80.002	22.487	16.202
59.999	14.060	10.152	70.002	9.547	6.878	80.002	27.032	19.482

Table B1. Continued .

t	S_A	Meas	t	S_A	Meas	t	S_A	Meas
°C	$g\,kg^{-1}$	$kg\,m^{-3}$	°C	$g\,kg^{-1}$	$kg\,m^{-3}$	°C	$g\,kg^{-1}$	$kg\,m^{-3}$
60.001	7.678	5.544	70.002	23.478	16.919	80.002	33.716	24.336
60.001	33.716	24.376	70.002	27.032	19.475	80.003	54.936	39.868
60.001	68.654	50.130	70.002	36.753	26.537	80.004	23.478	16.928
60.002	9.547	6.889	70.002	38.108	27.520	80.004	38.108	27.536
60.002	36.753	26.583	70.002	43.831	31.695	80.004	49.210	35.641
60.003	19.821	14.299	70.002	49.210	35.635	80.004	70.871	51.700
60.003	22.487	16.234	70.002	62.268	45.278	80.006	62.268	45.285
60.003	38.425	27.801	70.002	70.871	51.684	80.006	68.654	50.052
60.004	49.210	35.706	70.003	6.435	4.630	85.000	22.487	16.224
60.005	23.478	16.947	70.003	19.821	14.281	85.000	36.753	26.569
60.005	43.831	31.744	70.004	7.678	5.532	85.001	19.821	14.311
60.005	62.268	45.363	70.004	16.165	11.644	85.001	26.551	19.160
60.005	70.871	51.785	70.004	68.654	50.036	85.002	23.478	16.947
60.006	6.435	4.645	74.994	14.060	10.132	85.002	33.716	24.361
60.006	16.165	11.661	75.000	22.487	16.206	85.002	38.108	27.563
60.006	27.032	19.517	75.000	36.753	26.531	85.002	38.425	27.796
60.006	38.108	27.557	75.002	9.547	6.874	85.002	43.831	31.736
60.006	54.936	39.915	75.002	26.551	19.126	85.002	68.654	50.100
64.999	9.547	6.875	75.003	68.654	50.028	85.002	70.871	51.745
64.999	14.060	10.139	75.004	19.821	14.281	85.003	7.678	5.557
64.999	26.551	19.153	75.004	38.425	27.750	85.003	9.547	6.890
65.001	36.753	26.559	75.005	16.165	11.654	85.003	16.165	11.675
65.002	22.487	16.218	75.005	49.210	35.626	85.003	27.032	19.512
65.003	19.821	14.283	75.005	54.936	39.845	85.003	49.210	35.672
65.003	38.425	27.769	75.005	62.268	45.263	85.003	62.268	45.325
65.004	6.435	4.636	75.006	6.435	4.628	85.004	14.060	10.148
65.004	16.165	11.651	75.006	7.678	5.527	85.004	54.936	39.899
65.004	27.032	19.497	75.006	23.478	16.924	89.996	9.547	6.895
65.004	33.716	24.346	75.006	27.032	19.478	89.998	14.060	10.168
65.004	43.831	31.703	75.006	33.716	24.334	89.998	62.268	45.412
65.004	54.936	39.877	75.006	38.108	27.516	89.999	7.678	5.558
65.004	62.268	45.304	75.006	43.831	31.681	89.999	16.165	11.678
65.004	70.871	51.716	75.006	70.871	51.675	89.999	33.716	24.404
65.005	7.678	5.537	79.993	14.060	10.132	89.999	38.108	27.604
65.005	23.478	16.927	79.998	26.551	19.139	89.999	49.210	35.725
65.005	38.108	27.522	80.000	36.753	26.538	89.999	54.936	39.964
89.999	70.871	51.824						
90.000	23.478	16.970						
90.001	26.551	19.194						
90.001	36.753	26.612						
90.002	38.425	27.838						
90.003	19.821	14.332						
90.003	22.487	16.245						
89.999	49.210	35.725						
89.999	54.936	39.964						
89.999	70.871	51.824						
90.000	23.478	16.970						
90.001	26.551	19.194						
90.001	36.753	26.612						
90.002	38.425	27.838						
90.003	19.821	14.332						
90.003	22.487	16.245						

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