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The Practical Salinity Scale 1978: conversion of existing data

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Abstract—Implementation of the recommendations to adopt the Practical Salinity Scale 1978 (PSS 78) as a world standard will require examination of existing archived salinity data with a view to its conversion into the new scale. This study gives the basis for conversion to the PSS 78 from six of the most commonly used current salinity algorithms. It will enable oceanographers to assess whether or not changes are significant in terms of their interests.

INTRODUCTION

THE PRACTICAL SALINITY SCALE 1978 (PSS 78) has been considered by the Joint Panel on Oceanographic Tables and Standards and has now been recommended by SCOR, ICES, and IAPSO as the scale in which to report future salinity data. It is the basis of the new international equation of state and presumably its use will become standard at most oceanographic institutes in the near future. The PSS 78 and its antecedents have been described by LEWIS (1980). This paper addresses the question of how to compare new data to those already existing in institutional archives. Oceanographers having full information regarding their old data tabulations, including the equations used to reduce electrical conductivities to salinities and values for the bottle samples used for calibration, should be able to use this study to assess the magnitude of the change caused by conversion to the new scale.

LEWIS and PERKIN (1978) listed salinity algorithms used to reduce conductivity–temperature–depth (CTD) measurements and from these, six have been selected as commonly in use at the present time. They are described in UNESCO (1966), PERKIN and WALKER (1972), FOFONOFF, HAYES and MILLARD (1974), BENNETT (1976), RIBE and HOWE (1975), and FEDOROV (1971). All the sets of equations are based on the data of COX, CULKIN and RILEY (1967) or BROWN and ALLENTOFT (1966), or both, using the relationship by BRADSHAW and SCHLEICHER (1965) for the pressure dependence of conductivity ratios. The International Oceanographic Tables (UNESCO, 1966), based on the data of COX *et al.* (1967), do not go below 10°C, making them unsuited by themselves for *in situ* CTD data reduction. All the other equation sets referred to are based either on the BROWN and ALLENTOFT data alone or on a marriage of the two data sets. The sets are the results of experiments on water masses with differing ionic ratios and, as has been discussed by LEWIS (1980), are fundamentally incompatible. This leaves considerable freedom for interpretation in joining the sets together and so variability in calculated salinities. The original equations

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supplied with the data sets have been used by some authors; others have used the original data, refitted to different functional forms. This was examined by LEWIS and PERKIN (1978), who also gave a general discussion of the philosophy of salinity determination and emphasized the need for a new scale to provide an unambiguous basis for inter-institutional data comparisons. The recommended solution is the PSS 1978; this set of equations is given in the Appendix; an issue of the *Journal of Oceanic Engineering* (Vol. 5, January 1980) was devoted to the topic. All the other algorithms can be obtained from the references given.

An additional complication in salinity calculations is the change in the definition of practical temperature in 1968 (Comité International des Poids et Mésures, 1969). Before that date the International Practical Temperature Scale (1948) was in common use and temperatures measured on that scale and on the following International Practical Temperature Scale (1968) will be represented as T_{48} and T_{68}, respectively. The distinction between the two scales has been mentioned by the originators of salinity algorithms to whom it is important and a number of conversion equations have been derived, which, although algebraically different, give essentially the same correction. We have used each relationship within the context of its own paper.

In what follows, it is particularly important to distinguish between the given measured quantities, which must be assumed errorless, and derived quantities that are an artifact of a particular algorithm or procedure. Measured quantities will be denoted by *italic* type, e.g. *R*, *V*, *p*, and derived quantities in normal type. Temperature and pressure are considered measured quantities because they are derived from a single measured electrical parameter by a fixed procedure, unlike salinity, which is calculated from both of them as well as electrical conductivity in a variety of ways. The conductivity of a particular parcel of water in the ocean of salinity S, temperature *T* and applied pressure *p*, is defined as $\mathrm{C}(\mathrm{S}, T, p)$ and a pertinent parameter is the ratio between the conductivity and that of some standard seawater solution at a given temperature and pressure. The usual standard has been the conductivity of 35‰ seawater at a temperature of 15°C at atmospheric pressure, $\mathrm{C}(35, \mathit{15}, \mathit{0})$. In the various authors' formulations, $\mathrm{C}(35, \mathit{15}_{48}, \mathit{0})$ or $\mathrm{C}(35, \mathit{15}_{68}, \mathit{0})$ may be the 'constant' used and allowance for this must be made when changing temperature scales. The point has been discussed by BENNETT (1976).

Methods of applying corrections to old data depend not only on the equations used, but on the technique used to calibrate the instrument. The two common calibration practices are not equivalent in all regards and give different biases to the data sets to which they are applied. These are systematic and can be related to each other.

CALIBRATION TECHNIQUES FOR *IN SITU* MEASUREMENTS

The calibration of the *in situ* machine first involves placing limits of accuracy on temperature and pressure measurements, because these are independent variables. The *in situ* machine also provides an output voltage, *V*, or some other electrical analog, proportional to the ratio between the conductivity of the water (at its *in situ* temperature T^{i} and pressure *p*) and $\mathrm{C}(35, \mathit{15}, \mathit{0})$ thus:

$$\mathrm{R} = \frac{\mathrm{C}(\mathrm{S}, T^{\mathrm{i}}, p)}{\mathrm{C}(35, \mathit{15}, \mathit{0})} = \mathrm{K} \, . \, V(\mathrm{S}, T^{\mathrm{i}}, p), \tag{1}$$

where K is the cell constant, a function of the geometry of the cell. Next, a water sample collected at the same depth, location, and time the *in situ* reading was made is analysed in the bench salinometer to determine R_T, the ratio of the sample conductivity at temperature T to that of the standard seawater at the same temperature:

$$R_T = \mathrm{C}(\mathrm{S}, T, 0)/\mathrm{C}(35, T, 0). \tag{2}$$

In some bench salinometers the standard seawater and the sample are run successively into a conductivity cell within a constant temperature bath so that T of equation (2) is known and R_T is determined directly. In others, without thermostatic control, the temperature of the sample must still be measured, but it is specified that this temperature and that of the standard seawater must not differ by more than 3°C. Temperature differences up to this size are compensated for by an electronic network designed with knowledge of the temperature coefficient of the standard seawater,

$$\mathrm{r}_T = \mathrm{C}(35, T, 0)/\mathrm{C}(35, 15, 0). \tag{3}$$

The final piece of information required to complete the calibration process is the pressure dependence of the conductivity ratio:

$$\mathrm{R}_p = \frac{\mathrm{C}(\mathrm{S}, T^{\mathrm{i}}, p)}{\mathrm{C}(\mathrm{S}, T^{\mathrm{i}}, 0)} = [1 + \mathrm{P}(\mathrm{R}, T^{\mathrm{i}}, p)], \tag{4}$$

which allows connection between the *in situ* ratio and that which would have been measured on a bench salinometer at the same temperature. From (1), (2), (3), and (4),

$$\mathrm{R} = \mathrm{R}_p \mathrm{R}_T^{\mathrm{i}} \mathrm{r}_T^{\mathrm{i}}. \tag{5}$$

$\mathrm{R}_T^{\mathrm{i}}$ is solved for by an iterative process from the value of R_T measured by the bench salinometer (at temperature T) from knowledge of the form of its temperature dependence. As r_T and R_p are given functions, part of the salinity algorithm, R follows from equation (5) by a process of successive approximation. Thus the cell constant K is determined as a correction ΔK applied to the previous value. Once this has been done R can be considered as a measured quantity, R, and subsequent values for $\mathrm{R}_T^{\mathrm{i}}$ are calculated from (5). The final step is to calculate salinity from an equation of the form

$$\mathrm{S} = \mathrm{G}(\mathrm{R}_T, T), \tag{6}$$

which in practice determines 'salinity' for the scale. Formally, the definition of salinity is usually equation (6) for $T = 15$°C or its equivalent (see Appendix for the definition of 'practical salinity'). Differences between salinities calculated from the various algorithms involve differences in data bases and/or fittings for the forms of R_T, r_T, and R_p as well as the form of (6). This can be explicitly expressed as:

$$\begin{aligned} \mathrm{S} &= \mathrm{F}(R, T, p) \\ &= \mathrm{G}(R/\mathrm{R}_p \mathrm{r}_T, T) \text{ for } \textit{in situ} \text{ readings} \\ &= \mathrm{G}(R_T, T) \text{ when } p = 0 \text{ (bench salinometer).} \end{aligned} \tag{7}$$

The above method of *in situ* CTD calibration and use will be called the ΔK technique. However, many investigators, particularly those concerned with narrow salinity ranges, use an additive correction to salinity, the ΔS method. Salinities are calculated directly from the bench salinometer and *in situ* readings, R_T, and (R, T^{i}, p), respectively, using equation (7); the difference between these values constitutes ΔS, which is then added algebraically to all values of salinity calculated from subsequent *in situ* readings. As will be shown later, this common procedure is only exact at the salinity at which ΔS is calculated. It would have been better to apply a correction proportional to salinity rather than a fixed value.

The conversion of data that have been reduced using any of the six listed algorithms by either the ΔK or ΔS method to the PSS 78 will now be investigated in detail.

INSPECTION AND TESTING OF EXISTING DATA SETS

In the following discussion, salinities resulting from existing calculations, including the appropriate calibration corrections, will be denoted by S and corresponding practical salinities on the PSS 78 by S′. The actual quantity measured by the *in situ* instrument is a voltage or equivalent, which should be errorless and independent of any calibration process or salinity scale. Thus from (7) (dropping T and p from the notation as understood)

$$\mathrm{S} = \mathrm{F}(\mathrm{K}V), \qquad \mathrm{S}' = \mathrm{F}'(\mathrm{K}'V),$$

where K and K′ have been individually calculated on each scale, as described in the preceding section, by using $\mathrm{S} = \mathrm{G}(R_T)$ and $\mathrm{S}' = \mathrm{G}'(R_T)$ on the same bottle sample. S is measured in ‰, but this symbol has been omitted in the following discussion. Thus the change in salinity when converting to the PSS 78 is, from Taylor's expansion

$$\begin{aligned}\mathrm{S}'-\mathrm{S} &= \mathrm{F}'(\mathrm{K}'V)-\mathrm{F}(\mathrm{K}V)\\ &= \mathrm{F}'(\mathrm{K}'V)-\mathrm{F}(\mathrm{K}'V)-(\mathrm{K}-\mathrm{K}')V\,.\frac{\partial \mathrm{F}}{\partial \mathrm{R}}\\ &= \Delta\mathrm{F}-(1-\mathrm{K}'/\mathrm{K})\mathrm{R}\frac{\partial \mathrm{F}}{\partial \mathrm{R}}.\end{aligned}$$

It is seen that ΔF is the component of the salinity difference due to changing algorithms. Now $\mathrm{R}(\partial\mathrm{F}/\partial\mathrm{R})$ can be written as $\delta\mathrm{S}/(\delta\mathrm{R}/\mathrm{R})$ and $\delta\mathrm{R}/\mathrm{R}$ is almost independent of temperature and pressure for a given $\delta\mathrm{S}$. Thus, to the accuracy required, $\delta\mathrm{S}/(\delta\mathrm{R}/\mathrm{R})$ is independent of temperature and pressure and it can be demonstrated that it can be fitted to a quadratic,

$$\mathrm{R}(\partial\mathrm{F}/\partial\mathrm{R}) = \mathrm{aS}+\mathrm{bS}^2,$$

to within small limits. The values of the constants a and b are 1.0683 and 0.00156 with an r.m.s. deviation in $\mathrm{R}(\partial\mathrm{F}/\partial\mathrm{R})$ of 6×10^{-3}. Thus

$$\mathrm{S}'-\mathrm{S} = \Delta\mathrm{F}-(1-\mathrm{K}'/\mathrm{K})(\mathrm{aS}+\mathrm{bS}^2). \tag{8}$$

Taking the case of the bottle sample collected at specified values of V, T^{i}, and p and analysed on the bench to give R_T and T, (7) and (8) give

$$\mathrm{S}'-\mathrm{S} = \Delta\mathrm{G}_{\mathrm{B}} = \Delta\mathrm{F}_{\mathrm{B}}-(1-\mathrm{K}'/\mathrm{K})(\mathrm{aS}_{\mathrm{B}}+\mathrm{bS}_{\mathrm{B}}^2), \tag{9}$$

where the subscript B has been used to distinguish the bottle sample values. It is seen that $\Delta\mathrm{G}_{\mathrm{B}}$ is the salinity difference due to changing the algorithm used for the bench salinometer readings. Now $\Delta\mathrm{G}_{\mathrm{B}}$ and $\Delta\mathrm{F}_{\mathrm{B}}$ are known directly, hence $(1-\mathrm{K}'/\mathrm{K})$ can be calculated from (9) and applied to (8) to calculate $\mathrm{S}'-\mathrm{S}$ for any values of V, T^{i}, and p.

Table 1 lists the algorithms for which ΔF and ΔG corrections have been calculated along with their ranges of validity and information about conversion of temperature scales. A first estimate of the magnitude of the corrections is seen in Table 2 where $\Delta\mathrm{G}_{\mathrm{B}}$ has been listed for the International Tables. As the remaining five referenced sets of algorithms are close to

Table 1. *Review of the salinity algorithms considered, giving ranges of validity, and conversions needed for comparison with the Practical Salinity Scale* 1978

Salinity algorithm*	Ranges			Conversions		Reference
	Pressure (dbar)†	Temperature (°C)	Salinity	Temperature‡	Conductivity	Table No.
COX, CULKIN and RILEY (1967) (International Tables)	0	10 to 30 14 to 29*	4 to 42	—	—	2
FOFONOFF, HAYES and MILLARD (1974)	0 to 10,000	0 to 35 14 to 29*	4 to 42	$T_{68} \rightarrow T_{48}$	$R^{48} = 1.000106R^{68}$	3
PERKIN and WALKER (1972)	0 to 1,700	Freezing to 20	4 to 40	$T_{68} \rightarrow T_{48}$	$C^{48} = 42.9284R^{68}$	4
BENNETT (1976)	0 to 10,000	Freezing to 35	4 to 42	—	—	5
RIBE and HOWE (1975)§	0 to 7,000	0 to 30	20 to 40	—	—	6
FEDOROV (1971)§	0 to 2,000	0 to 30	33 to 37	—	—	7

* Range of data. FOFONOFF *et al.* (1974) state that their algorithm works at temperatures below 14°C (see Table 3).

† 1 dbar = 10 kilopascals.

‡ $T_{48} = T_{68}\,(1.000488 - 5.80 \times 10^{-6} T_{68})$.

§ Conversion of temperature scale omitted because of unclear or missing notification. It is thought that most investigators will have used the uncorrected formulation given here.

Table 2. The salinity difference in ‰ × 10^3 calculated by the PSS 78 minus that given by the International Tables starting from the same measured values of R_T *and* T

Pressure, 0 dbar

Temperature, °C \ Salinity, ppt	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
34	+23	+29	+39	+44	+45	+41	+35	+28	+21	+15	+9	+6	+3	+2	+1	+1	+0	−1	−2	−5	−8
32	+22	+28	+38	+43	+44	+40	+35	+28	+21	+15	+10	+6	+4	+3	+2	+1	+0	−1	−3	−6	−10
30	+22	+27	+37	+42	+43	+40	+34	+28	+21	+15	+11	+7	+5	+3	+2	+2	+1	−1	−3	−6	−10
28	+21	+26	+36	+41	+42	+39	+34	+27	+21	+15	+11	+7	+5	+4	+3	+2	+1	−1	−3	−7	−11
26	+21	+25	+35	+40	+41	+38	+33	+27	+21	+16	+11	+8	+6	+4	+3	+2	+1	−1	−4	−7	−11
24	+21	+25	+34	+39	+40	+38	+33	+27	+21	+16	+12	+8	+6	+5	+3	+2	+1	−1	−4	−7	−12
22	+20	+24	+33	+39	+40	+37	+33	+27	+21	+16	+12	+9	+6	+5	+4	+2	+1	−1	−4	−7	−12
20	+20	+23	+32	+38	+39	+37	+32	+27	+21	+16	+12	+9	+7	+5	+4	+3	+1	−1	−4	−8	−11
18	+20	+23	+32	+38	+39	+37	+33	+27	+22	+17	+13	+10	+7	+6	+4	+3	+1	−1	−4	−8	−11
16	+20	+23	+32	+38	+39	+37	+33	+28	+23	+18	+14	+10	+8	+6	+5	+3	+1	−1	−4	−8	−11
14	+20	+23	+32	+38	+39	+38	+34	+29	+23	+19	+15	+11	+9	+7	+5	+3	+1	−1	−4	−8	−11
12	+20	+23	+32	+38	+40	+39	+35	+30	+25	+20	+16	+13	+10	+8	+6	+4	+1	−1	−4	−8	−11
10	+21	+24	+33	+39	+41	+40	+36	+32	+27	+22	+18	+14	+11	+9	+6	+4	+1	−2	−5	−8	−11
8	+21	+25	+34	+41	+43	+42	+39	+34	+29	+24	+20	+16	+13	+10	+7	+4	+2	−2	−5	−8	−11
6	+22	+26	+36	+43	+46	+45	+42	+37	+32	+27	+23	+19	+15	+12	+8	+5	+2	−2	−6	−9	−12
4	+24	+28	+39	+46	+49	+49	+46	+41	+36	+31	+27	+22	+18	+14	+10	+6	+2	−2	−6	−10	−13
2	+25	+31	+42	+50	+54	+53	+51	+47	+41	+36	+31	+26	+21	+17	+12	+7	+2	−2	−7	−11	−14
0	+27	+34	+46	+55	+59	+59	+57	+53	+48	+42	+37	+31	+26	+20	+15	+9	+3	−3	−9	−14	−17
−2	+29	+38	+51	+61	+66	+67	+65	+61	+56	+50	+44	+37	+31	+24	+18	+11	+4	−4	−10	−16	−20

Salinity, ppt

* Dashed line encloses the region of validity of the equations as given in Table 1.

the International Tables over that part of their range (two of them are identical), Table 2 is a good guide to what is to follow. The values of ΔG_B are mostly the result of ionic ratio differences between the waters giving rise to the two data sets used and this has been discussed by LEWIS (1980). Both data sets have the IAPSO standard seawater in common which in the past, with few exceptions, has been good as a conductivity standard within ± 0.002 salinity (POISSON, DAUPHINEE, ROSS and CULKIN, 1978) and at $S = 35$, $\Delta G \sim 0.0$ independent of temperature.

Tables 3 to 7 give the salinity differences, ΔF, at various pressures between the PSS 78 and the five remaining salinity algorithms calculated from the same measured values. ΔG_B is tabulated in each case for three laboratory temperatures, 16, 20, and 24°C. Except in extreme cases, linear interpolation between values in the tables is sufficient to give an accuracy of ± 2 ppm for $S' - S$. The use of the tables is best described by giving an example.

Consider a profile where a bottle sample has been taken at 1000 dbar pressure and temperature 0°C. The sample has been analysed aboard ship at a temperature of 20°C to give a salinity of 36 by the algorithm due to FOFONOFF *et al.* (1974), which has then been used to compute profile salinities corrected by the ΔK method. At 20-m depth in the profile the salinity so computed is 28 at a temperature of 4°C. What salinity would have been computed if PSS 78 had been used throughout?

Referring to Table 3 (FOFONOFF *et al.*, 1974), the parameters for the bottle sample ($T = 0°C$, $S = 36$, $p = 1000$ dbar) give $\Delta G_B = -1 \times 10^{-3}$, $\Delta F_B = -13 \times 10^{-3}$, and $aS + bS^2 = 40$. Thus (9) gives

$$(1 - K'/K) = (-13 + 1)10^{-3}/40 = -30 \times 10^{-5}.$$

Referring to Table 3 (0 dbar) for the profile point of interest ($T = 4°C$, $S = 28‰$), $\Delta F = 15 \times 10^{-3}$ and $aS + bS^2 = 31$. Equation (8) then gives

$$S' - S = 15 \times 10^{-3} + 30 \times 10^{-5} \times 31 = 24 \times 10^{-3}.$$

Therefore, salinities at this point of the profile would have been 0.024 higher if PSS 78 had been used.

The ΔS calibration technique is differently formulated: the *in situ* salinity is forced to agree with the corresponding bottle sample value at any point in the profile:

$$S = F(R) + \Delta S$$

where

$$\Delta S = G_B - F(R_B).$$

Using the same measured values but the PSS 78

$$S' = F'(R) + G'_B - F'(R_B)$$

where R is a measured value. Thus:

$$S' - S = F'(R) - F(R) - [F'(R_B) - F(R_B)] + G'_B - G_B,$$

or

$$S' - S = \Delta F - \Delta F_B + \Delta G_B. \tag{10}$$

Taking the same example, ΔG_B, ΔF_B, and ΔF remain unchanged at -1×10^{-3}, -13×10^{-3}, and 15×10^{-3} respectively. From (10)

$$S' - S = 15 + 13 - 1 = 27 \times 10^{-3}.$$

Table 3. Values for ΔF (‰ × 10^3), the salinity difference between the PSS 78 and FOFONOFF et al. (1974) *calculated from the same measured values at pressures of* 0, 1000, 2000, *and* 5000 *dbar*

Pressure, 0 dbar

Temperature, °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
34	+22	+28	+38	+43	+43	+39	+33	+26	+18	+12	+6	+2	+0	−2	−3	−4	−5	−6	−8	−11	−15
32	+22	+28	+38	+43	+44	+40	+34	+28	+21	+15	+10	+6	+4	+2	+2	+1	+0	−1	−3	−6	−10
30	+22	+27	+37	+43	+44	+41	+35	+29	+22	+17	+12	+9	+6	+5	+4	+4	+3	+2	−1	−4	−8
28	+22	+26	+36	+42	+43	+40	+35	+29	+23	+17	+13	+10	+8	+7	+6	+5	+4	+3	+1	−3	−7
26	+21	+26	+35	+41	+42	+40	+35	+29	+23	+18	+13	+10	+8	+7	+6	+6	+5	+3	+0	−3	−7
24	+21	+25	+34	+40	+41	+39	+34	+28	+23	+18	+14	+10	+8	+7	+6	+5	+4	+2	+0	−4	−8
22	+20	+24	+33	+39	+40	+38	+34	+28	+22	+17	+13	+10	+8	+7	+6	+5	+3	+1	−1	−5	−9
20	+20	+24	+33	+38	+40	+37	+33	+28	+22	+17	+13	+10	+8	+6	+5	+4	+2	+0	−3	−6	−10
18	+20	+23	+32	+38	+39	+37	+33	+27	+22	+17	+13	+10	+8	+6	+5	+3	+1	−1	−4	−7	−11
16	+20	+23	+32	+38	+39	+37	+33	+28	+23	+18	+14	+10	+8	+6	+5	+3	+1	−1	−4	−7	−11
14	+20	+23	+32	+38	+39	+38	+34	+29	+24	+19	+15	+11	+9	+7	+5	+3	+1	−1	−4	−7	−11
12	+20	+23	+32	+38	+40	+39	+35	+30	+25	+20	+16	+13	+10	+8	+6	+4	+2	−1	−4	−7	−10
10	+21	+24	+33	+40	+42	+40	+37	+32	+27	+23	+19	+15	+12	+10	+8	+5	+3	+0	−3	−6	−9
8	+22	+25	+35	+41	+44	+43	+40	+35	+30	+26	+21	+18	+15	+12	+9	+7	+4	+1	−3	−6	−8
6	+23	+27	+37	+44	+46	+46	+43	+38	+34	+29	+24	+21	+17	+14	+11	+8	+4	+1	−3	−6	−8
4	+24	+29	+39	+46	+50	+49	+46	+42	+37	+32	+28	+23	+19	+15	+12	+8	+4	+0	−4	−8	−11
2	+25	+31	+42	+50	+53	+53	+50	+46	+41	+35	+30	+25	+20	+15	+11	+6	+1	−4	−9	−13	−16
0	+27	+33	+44	+53	+57	+56	+54	+49	+43	+37	+31	+25	+19	+13	+7	+1	−6	−12	−18	−24	−28
−2	+28	+35	+47	+56	+60	+59	+56	+51	+45	+37	+30	+23	+15	+7	−1	−9	−18	−26	−34	−42	−47

Salinity, ppt

Table 3—continued

Temperature, °C	1000 dbar						2000 dbar						5000 dbar					
	30	32	34	36	38	40	30	32	34	36	38	40	30	32	34	36	38	40
36																		
34																		
32	−5	−6	−7	−9	−12	−16	−10	−11	−13	−16	−20	−24	−17	−19	−22	−26	−31	−38
30	+1	+0	−1	−3	−6	−10	−1	−3	−4	−7	−10	−15	−4	−6	−8	−12	−17	−23
28	+5	+4	+3	+1	−2	−6	+4	+3	+1	−1	−5	−9	+5	+3	+1	−2	−7	−13
26	+7	+6	+4	+2	−1	−5	+7	+6	+4	+2	−2	−6	+11	+9	+7	+3	−2	−8
24	+8	+6	+5	+3	−1	−5	+9	+8	+6	+3	−1	−6	+14	+12	+9	+6	+1	−6
22	+8	+6	+5	+2	−1	−6	+9	+8	+6	+3	−1	−6	+15	+13	+10	+6	+1	−6
20	+7	+6	+4	+1	−2	−7	+9	+7	+5	+2	−2	−7	+15	+13	+10	+5	+0	−7
18	+7	+5	+3	+0	−4	−8	+9	+7	+4	+1	−4	−9	+14	+12	+8	+4	−2	−9
16	+7	+5	+2	−1	−5	−9	+8	+6	+3	+0	−5	−10	+14	+11	+7	+2	−4	−12
14	+7	+5	+2	−1	−5	−10	+8	+6	+3	−1	−6	−12	+13	+10	+6	+1	−6	−14
12	+8	+5	+2	−1	−5	−10	+9	+6	+3	−1	−7	−12	+14	+10	+6	+0	−7	−15
10	+9	+6	+3	−1	−5	−10	+10	+7	+3	−1	−7	−13	+15	+11	+6	+0	−8	−16
8	+10	+7	+4	+0	−5	−10	+12	+8	+4	−1	−7	−13	+16	+12	+7	+0	−8	−18
6	+12	+8	+4	+0	−5	−10	+13	+9	+4	−1	−7	−14	+18	+13	+7	+0	−9	−19
4	+13	+9	+4	−2	−7	−13	+15	+10	+4	−2	−9	−16	+19	+14	+7	−2	−11	−22
2	+13	+7	+1	−5	−12	−18	+14	+8	+2	−6	−14	−22	+19	+13	+4	−5	−16	−28
0	+9	+2	−5	−13	−21	−29	+11	+4	−4	−13	−23	−33	+16	+8	−2	−13	−26	−40
−2	+1	−8	−17	−27	−37	−47	+4	−6	−16	−27	−39	−51	+9	−2	−14	−28	−43	−59
−4																		

Salinity, ppt

Salinity, ppt	16	20	24
42	−11	−11	−12
40	−8	−8	−7
38	−4	−4	−4
36	−1	−1	−1
34	+1	+1	+1
32	+3	+3	+2
30	+5	+4	+3
28	+6	+5	+5
26	+8	+7	+6
24	+10	+9	+8
22	+14	+12	+12
20	+18	+16	+16
18	+23	+21	+21
16	+28	+27	+27
14	+33	+32	+33
12	+37	+37	+38
10	+39	+39	+40
8	+38	+38	+39
6	+32	+32	+34
4	+23	+23	+25
2	+20	+20	+21

°C

ΔG_B

ΔG_B at the lower right of Tables 3 to 7 gives the calculated change in bottle sample salinities used for calibration purposes. See text for discussion and method of use. Dashed line encloses the region of validity of the equations as given in Table 1.

Table 4. Values for ΔF (‰ × 10^3), the salinity difference between the PSS 78 and Perkin *and* Walker *(1972) calculated from the same measured values at pressures of* 0, 500, 1000, *and* 2000 *dbar*

Pressure, 0 dbar

Temperature, °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
36																					
34	+46	-9	-28	-32	-32	-34	-37	-38	-36	-31	-26	-20	-13	-7	+0	+7	+14	+23	+34	+49	+68
32	+49	-4	-22	-25	-24	-25	-28	-29	-27	-23	-19	-14	-9	-4	+1	+6	+11	+17	+26	+38	+55
30	+52	+0	-16	-19	-17	-17	-20	-22	-20	-17	-13	-9	-5	-2	+1	+4	+8	+12	+19	+28	+43
28	+54	+3	-12	-14	-12	-12	-14	-16	-15	-12	-9	-6	-3	+0	+2	+3	+5	+8	+13	+21	+33
26	+55	+6	-9	-10	-7	-7	-10	-12	-11	-8	-6	-3	-1	+1	+2	+3	+3	+5	+8	+14	+25
24	+56	+7	-6	-7	-4	-4	-6	-8	-7	-5	-3	-1	+0	+1	+2	+2	+2	+2	+5	+9	+18
22	+56	+8	-5	-5	-2	-1	-4	-6	-5	-3	-2	+0	+1	+2	+2	+1	+1	+1	+2	+6	+13
20	+56	+9	-4	-4	+0	+0	-2	-4	-4	-2	-1	+1	+2	+2	+2	+1	+0	+0	+0	+3	+10
18	+56	+9	-3	-3	+1	+1	-1	-3	-3	-2	+0	+1	+2	+2	+2	+1	+0	+0	+0	+2	+7
16	+55	+9	-3	-3	+1	+2	-1	-3	-3	-2	+0	+1	+2	+2	+2	+2	+1	+0	+0	+1	+5
14	+55	+8	-4	-3	+1	+2	-1	-3	-3	-2	-1	+0	+1	+2	+2	+2	+1	+1	+0	+1	+4
12	+54	+8	-4	-4	+0	+1	-1	-4	-4	-3	-1	+0	+1	+2	+2	+3	+2	+2	+1	+1	+4
10	+53	+7	-5	-4	-1	+1	-2	-4	-4	-3	-2	-1	+0	+1	+2	+3	+3	+3	+2	+2	+3
8	+52	+6	-6	-5	-1	+0	-2	-5	-5	-4	-3	-2	-1	+1	+2	+3	+4	+3	+2	+1	+1
6	+50	+5	-7	-6	-2	-1	-3	-6	-6	-5	-5	-3	-2	+0	+1	+3	+4	+3	+2	+0	-1
4	+49	+5	-7	-6	-2	-1	-3	-6	-7	-7	-6	-5	-4	-2	+0	+2	+2	+2	+0	-2	-6
2	+48	+4	-7	-6	-2	-1	-4	-7	-8	-8	-8	-7	-6	-4	-2	-1	+0	-1	-3	-8	-13
0	+51	+8	-4	-2	+2	+3	+0	-3	-5	-6	-6	-6	-6	-4	-3	-1	-1	-3	-7	-13	-21
-2	+70	+27	+16	+18	+22	+23	+20	+16	+14	+12	+11	+10	+10	+10	+11	+12	+11	+8	+2	-6	-17
-4																					

0

Salinity, ppt

Table 4—continued

Temperature, °C	500 dbar						1000 dbar						2000 dbar					
36																		
34																		
32	−4	+0	+5	+10	+18	+29	−5	−1	+3	+8	+15	+26	+3	+7	+10	+15	+22	+32
30	−3	−1	+2	+5	+11	+20	−4	−2	+0	+3	+8	+16	+4	+6	+8	+11	+15	+23
28	−3	−2	−1	+1	+5	+12	−4	−4	−3	−1	+2	+8	+5	+6	+6	+7	+10	+16
26	−3	−3	−3	−2	+0	+5	−4	−4	−5	−5	−3	+2	+6	+5	+5	+5	+6	+10
24	−3	−4	−5	−5	−4	+0	−4	−5	−6	−7	−7	−3	+7	+6	+4	+3	+3	+6
22	−3	−4	−6	−7	−6	−3	−4	−6	−7	−9	−9	−7	+8	+6	+4	+2	+1	+3
20	−3	−5	−6	−8	−8	−6	−4	−6	−8	−10	−11	−9	+8	+6	+4	+2	+1	+2
18	−3	−5	−7	−8	−9	−8	−4	−6	−8	−10	−12	−11	+9	+7	+5	+3	+1	+1
16	−4	−5	−6	−8	−9	−9	−4	−6	−8	−10	−12	−12	+10	+8	+6	+4	+2	+1
14	−4	−5	−6	−8	−9	−9	−4	−6	−7	−10	−11	−12	+11	+10	+8	+5	+3	+2
12	−4	−4	−6	−7	−8	−9	−4	−5	−7	−9	−11	−12	+12	+11	+9	+7	+5	+4
10	−4	−4	−5	−6	−8	−9	−4	−5	−6	−8	−10	−12	+12	+12	+11	+9	+7	+5
8	−5	−4	−5	−6	−8	−10	−5	−5	−6	−8	−10	−13	+13	+13	+12	+10	+8	+6
6	−6	−5	−5	−7	−9	−11	−6	−6	−7	−8	−11	−14	+12	+13	+12	+11	+8	+5
4	−8	−7	−7	−8	−11	−15	−8	−8	−9	−10	−14	−18	+11	+12	+12	+10	+7	+3
2	−11	−10	−10	−12	−16	−21	−12	−11	−12	−14	−18	−24	+9	+10	+9	+8	+4	−2
0	−12	−12	−12	−15	−20	−27	−13	−13	−14	−17	−22	−30	+8	+9	+8	+6	+1	−7
−2	+1	+0	−1	−5	−12	−21	−1	−1	−4	−8	−15	−25	+21	+21	+20	+16	+9	+0
−4																		
0	30	32	34	36	38	40	30	32	34	36	38	40	30	32	34	36	38	40

Salinity, ppt

Salinity, ppt			
42	+6	+10	+16
40	+1	+3	+7
38	+0	+0	+2
36	+0	+0	+0
34	+1	+0	+0
32	+2	+1	+0
30	+2	+2	+0
28	+2	+2	+0
26	+2	+2	−1
24	+1	+1	−3
22	+0	−1	−4
20	−2	−2	−7
18	−3	−4	−9
16	−3	−4	−9
14	−1	−2	−7
12	+2	+0	−4
10	+1	+0	−5
8	−3	−3	−7
6	−3	−4	−7
4	+9	+9	+7
2	+55	+56	+56
	16	20	24

°C

ΔG_B

See footnote to Table 3.

Table 5. Values for ΔF (‰ × 10^3), the salinity difference between the PSS 78 and Bennett *(1976) calculated from the same measured values at pressures of* 0, 1000, 2000, *and* 5000 *dbar*

Pressure, 0 dbar

Temperature, °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
34	+18	+20	+28	+31	+31	+27	+21	+13	+6	+0	−6	−11	−15	−17	−20	−22	−24	−26	−28	−30	−32
32	+20	+23	+32	+37	+37	+35	+30	+23	+17	+12	+7	+3	+0	−2	−3	−5	−6	−8	−10	−11	−13
30	+20	+25	+34	+40	+41	+39	+35	+29	+24	+19	+14	+11	+9	+7	+6	+4	+3	+2	+0	−2	−3
28	+21	+25	+35	+41	+43	+41	+37	+32	+27	+22	+18	+15	+12	+11	+9	+8	+7	+5	+3	+1	−1
26	+21	+25	+35	+42	+43	+42	+38	+33	+27	+23	+19	+15	+13	+11	+10	+9	+7	+5	+3	+1	−2
24	+21	+25	+35	+41	+43	+41	+37	+32	+27	+22	+18	+15	+12	+10	+9	+7	+5	+3	+1	−2	−5
22	+21	+25	+34	+40	+42	+40	+36	+31	+26	+21	+17	+14	+11	+9	+7	+5	+3	+1	−2	−5	−8
20	+21	+24	+34	+40	+41	+39	+35	+30	+25	+20	+16	+12	+10	+7	+6	+4	+2	−1	−4	−7	−10
18	+20	+24	+33	+39	+40	+38	+34	+29	+24	+19	+15	+11	+9	+7	+5	+3	+1	−2	−5	−8	−11
16	+20	+23	+32	+38	+39	+38	+34	+28	+23	+18	+14	+11	+8	+6	+5	+3	+1	−2	−5	−8	−11
14	+20	+23	+32	+37	+39	+37	+33	+28	+23	+18	+14	+11	+8	+7	+5	+3	+1	−1	−4	−7	−10
12	+20	+22	+31	+37	+38	+36	+32	+27	+22	+18	+14	+11	+9	+7	+6	+4	+2	+0	−2	−6	−9
10	+20	+22	+30	+36	+38	+36	+32	+27	+22	+18	+14	+11	+9	+7	+6	+5	+3	+1	−2	−5	−8
8	+20	+22	+30	+35	+37	+35	+31	+26	+21	+17	+13	+10	+8	+7	+6	+4	+3	+1	−2	−5	−8
6	+19	+21	+29	+35	+36	+34	+30	+25	+20	+16	+12	+9	+7	+6	+4	+3	+1	−1	−3	−6	−10
4	+19	+21	+29	+34	+36	+34	+30	+25	+19	+15	+11	+8	+6	+4	+2	+1	−1	−3	−6	−9	−13
2	+20	+21	+29	+34	+36	+34	+29	+24	+19	+14	+10	+7	+4	+2	+1	−1	−3	−6	−9	−13	−17
0	+20	+22	+30	+35	+37	+35	+31	+26	+20	+16	+11	+8	+5	+3	+1	−1	−4	−7	−11	−15	−19
−2	+21	+24	+33	+39	+41	+39	+36	+31	+26	+21	+17	+14	+11	+9	+7	+5	+2	−2	−6	−10	−15

Salinity, ppt

Table 5—continued

Temperature, °C	1000 dbar						2000 dbar						5000 dbar					
	30	32	34	36	38	40	30	32	34	36	38	40	30	32	34	36	38	40
36																		
34																		
32	−2	−3	−4	−5	−6	−7	−2	−2	−3	−4	−5	−5	−3	−4	−4	−5	−6	−7
30	+7	+6	+6	+4	+3	+2	+8	+7	+7	+6	+5	+4	+8	+7	+6	+4	+3	+1
28	+11	+10	+9	+8	+6	+5	+13	+12	+11	+9	+8	+6	+14	+12	+10	+8	+5	+2
26	+12	+11	+10	+8	+6	+4	+14	+13	+11	+9	+7	+5	+17	+14	+11	+8	+4	+0
24	+11	+10	+8	+6	+4	+1	+13	+12	+10	+8	+5	+2	+17	+14	+10	+6	+1	−4
22	+10	+8	+6	+4	+1	−2	+12	+10	+8	+5	+2	−1	+17	+13	+9	+4	−2	−8
20	+9	+7	+5	+2	−1	−4	+11	+9	+6	+3	+0	−4	+17	+12	+7	+2	−5	−12
18	+8	+6	+4	+1	−2	−6	+10	+8	+6	+2	−1	−5	+17	+12	+7	+0	−6	−14
16	+8	+6	+4	+1	−2	−6	+10	+8	+5	+2	−2	−6	+17	+12	+7	+0	−7	−15
14	+8	+6	+4	+2	−1	−5	+11	+8	+6	+3	−1	−5	+18	+13	+7	+1	−7	−15
12	+8	+7	+5	+3	+0	−4	+11	+9	+7	+4	+0	−4	+19	+14	+8	+1	−6	−14
10	+8	+7	+5	+3	+0	−3	+11	+9	+7	+4	+0	−4	+18	+14	+8	+2	−6	−14
8	+8	+6	+5	+2	+0	−3	+10	+8	+6	+3	+0	−4	+17	+13	+7	+1	−6	−15
6	+6	+4	+3	+1	−2	−5	+7	+6	+4	+1	−2	−6	+15	+10	+5	−1	−9	−17
4	+3	+2	+0	−3	−5	−9	+4	+2	+0	−2	−6	−10	+11	+7	+2	−5	−12	−20
2	+0	−1	−3	−6	−9	−13	+1	−1	−3	−6	−10	−14	+7	+3	−2	−8	−16	−24
0	−1	−3	−5	−7	−11	−15	−1	−3	−5	−8	−12	−16	+5	+1	−4	−10	−17	−25
−2	+4	+2	+0	−3	−6	−10	+2	+1	−1	−4	−7	−11	+8	+4	+0	−5	−12	−19
−4																		

Salinity, ppt

Salinity, ppt	16	20	24
42	−11	−11	−10
40	−8	−8	−7
38	−4	−4	−4
36	−1	−1	−1
34	+1	+1	+1
32	+3	+3	+3
30	+5	+5	+5
28	+7	+7	+7
26	+9	+9	+9
24	+11	+12	+12
22	+14	+15	+15
20	+18	+20	+20
18	+23	+24	+25
16	+29	+30	+30
14	+34	+35	+36
12	+38	+39	+40
10	+40	+41	+42
8	+38	+39	+40
6	+32	+33	+34
4	+23	+24	+25
2	+20	+20	+21

°C

ΔG_B

See footnote to Table 3.

Table 6. Values for ΔF ($‰ \times 10^3$), *the salinity difference between the PSS* 78 *and* Ribe *and* Howe (1975) *calculated from the same measured values at pressures* of 0, 1000, 2000, *and* 5000 *dbar*

Pressure, 0 dbar

Temperature, °C \ Salinity, ppt	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
36																						
34					+88	+49	+22	+5	−5	−11	−14	−15	−14	−13	−11	−10	−9	−8	−7	−8	−9	−10
32					+98	+58	+32	+15	+4	−2	−6	−7	−7	−6	−5	−4	−3	−3	−3	−4	−5	−7
30						+66	+40	+22	+11	+4	+1	−1	−1	−1	+0	+0	+1	+0	+0	−2	−4	−6
28						+74	+46	+28	+17	+10	+6	+4	+3	+3	+3	+3	+3	+2	+1	−1	−3	−6
26						+80	+52	+33	+21	+14	+9	+7	+5	+5	+4	+4	+3	+2	+1	−1	−4	−7
24						+85	+57	+38	+25	+17	+12	+9	+7	+6	+5	+4	+3	+2	+0	−2	−5	−8
22						+90	+61	+41	+28	+19	+14	+10	+8	+6	+5	+4	+3	+1	−1	−3	−6	−9
20						+94	+64	+44	+30	+21	+15	+11	+8	+7	+5	+4	+2	+1	−1	−4	−7	−10
18						+97	+67	+46	+32	+22	+16	+12	+9	+7	+5	+4	+2	+0	−2	−5	−7	−11
16						+99	+68	+47	+33	+23	+16	+12	+9	+7	+5	+4	+2	+0	−2	−5	−7	−10
14						+99	+69	+48	+33	+24	+17	+12	+9	+7	+5	+4	+2	+0	−2	−4	−7	−9
12						+98	+68	+47	+33	+23	+17	+13	+10	+8	+6	+5	+3	+1	−1	−3	−5	−8
10						+95	+66	+45	+32	+22	+16	+13	+10	+8	+7	+6	+4	+3	+1	−1	−4	−6
8						+88	+60	+41	+28	+20	+15	+12	+10	+8	+7	+6	+5	+4	+2	+0	−2	−5
6						+77	+51	+34	+23	+16	+12	+10	+9	+8	+8	+7	+6	+5	+3	+1	−1	−4
4					+96	+60	+37	+22	+13	+9	+6	+6	+6	+6	+6	+6	+6	+5	+3	+1	−2	−6
2					+67	+36	+16	+5	−1	−3	−3	−2	+0	+2	+3	+4	+3	+2	+0	−3	−6	−11
0				+70	+27	+1	−14	−20	−22	−21	−17	−14	−10	−6	−4	−3	−3	−4	−6	−10	−15	−21
−2			+69	+7	−29	−48	−55	−56	−52	−46	−39	−32	−26	−20	−17	−14	−14	−16	−19	−24	−31	−39
−4																						

Table 6—continued

Temperature, °C	1000 dbar						2000 dbar						5000 dbar					
	30	32	34	36	38	40	30	32	34	36	38	40	30	32	34	36	38	40
36																		
34																		
32	+0	+1	+1	+1	+0	−2	+4	+5	+5	+5	+3	+1	+14	+15	+15	+14	+12	+10
30	+4	+4	+4	+3	+1	−1	+7	+8	+7	+6	+4	+1	+16	+17	+16	+15	+12	+8
28	+6	+6	+5	+3	+1	−2	+9	+9	+8	+6	+4	+0	+17	+17	+16	+14	+10	+6
26	+7	+6	+5	+3	+0	−3	+10	+9	+7	+5	+2	−1	+17	+16	+15	+12	+8	+3
24	+7	+5	+4	+2	−1	−5	+9	+8	+6	+4	+0	−4	+16	+15	+13	+10	+5	+0
22	+6	+5	+3	+0	−3	−7	+9	+7	+5	+2	−2	−6	+15	+14	+11	+7	+2	−4
20	+5	+4	+2	−1	−4	−8	+8	+6	+3	+0	−4	−8	+14	+12	+9	+5	+0	−7
18	+5	+3	+1	−2	−6	−9	+7	+5	+2	−1	−5	−10	+13	+11	+7	+3	−3	−9
16	+4	+2	+0	−3	−6	−10	+6	+4	+1	−2	−6	−11	+12	+10	+6	+2	−4	−11
14	+4	+2	+0	−3	−6	−10	+6	+4	+1	−2	−7	−11	+12	+10	+6	+1	−5	−12
12	+5	+3	+0	−2	−6	−10	+7	+4	+1	−2	−6	−11	+13	+10	+6	+1	−5	−12
10	+6	+4	+1	−1	−5	−9	+7	+5	+2	−2	−6	−11	+14	+11	+7	+2	−4	−12
8	+6	+5	+2	−1	−4	−8	+8	+6	+3	−1	−5	−11	+15	+13	+9	+4	−3	−11
6	+6	+5	+3	+0	−4	−8	+8	+6	+3	+0	−5	−11	+16	+14	+10	+5	−3	−11
4	+6	+4	+2	−1	−5	−10	+7	+6	+3	−1	−7	−13	+16	+14	+10	+5	−3	−13
2	+3	+2	−1	−4	−9	−15	+4	+3	+0	−5	−11	−18	+15	+13	+9	+3	−6	−17
0	−4	−5	−7	−11	−17	−24	−2	−3	−7	−12	−19	−28	+10	+9	+4	−3	−13	−26
−2	−16	−17	−19	−24	−32	−41	−14	−15	−19	−25	−34	−45	+1	+0	−5	−14	−26	−41
−4																		

Salinity, ppt

Salinity, ppt	16	20	24
42	−9	−10	−10
40	−6	−6	−6
38	−3	−4	−3
36	−1	−1	−1
34	+1	+1	+1
32	+3	+3	+2
30	+4	+4	+3
28	+6	+6	+4
26	+8	+7	+5
24	+10	+9	+6
22	+13	+11	+8
20	+17	+15	+11
18	+24	+21	+16
16	+33	+30	+24
14	+48	+44	+37
12	+69	+64	+56
10	+99	+94	+85
8			
6			
4			
2			

°C
ΔG_B

See footnote to Table 3.

Table 7. Values for ΔF ($‰ \times 10^3$), the salinity difference between the PSS 78 and FEDOROV (1971) *calculated from the same measured values at pressures of* 0, 500, 1000, *and* 2000 *dbar*

Pressure, 0 dbar

Temperature, °C \ Salinity, ppt	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
34	+28	+38	+53	+64	+69	+70	+69	+67	+65	+64	+64	+65	+68	+72	+77	+81	+86	+90	+94	+97	+99
32	+26	+34	+48	+57	+61	+61	+58	+55	+51	+49	+47	+47	+48	+50	+53	+56	+59	+61	+63	+64	+64
30	+24	+31	+43	+51	+53	+52	+49	+44	+40	+36	+34	+32	+32	+33	+34	+36	+37	+38	+38	+37	+35
28	+22	+28	+39	+46	+47	+46	+41	+36	+31	+26	+23	+21	+20	+19	+20	+20	+20	+20	+18	+16	+13
26	+21	+26	+36	+42	+43	+41	+36	+30	+24	+19	+15	+12	+11	+10	+9	+8	+7	+5	+4	+1	-3
24	+20	+24	+33	+39	+40	+37	+32	+26	+20	+15	+10	+7	+5	+3	+2	+1	-1	-3	-6	-9	-14
22	+20	+23	+32	+37	+38	+35	+30	+24	+18	+12	+8	+4	+2	+0	-2	-3	-5	-8	-11	-15	-19
20	+20	+23	+31	+36	+37	+34	+29	+24	+18	+12	+8	+4	+1	-1	-3	-4	-6	-9	-12	-16	-21
18	+20	+22	+31	+36	+37	+35	+30	+25	+19	+14	+9	+6	+3	+1	-1	-3	-5	-7	-11	-14	-19
16	+20	+23	+31	+37	+38	+36	+32	+27	+21	+16	+12	+9	+6	+4	+3	+1	-1	-4	-7	-10	-14
14	+20	+23	+32	+38	+40	+38	+35	+30	+25	+20	+16	+13	+11	+9	+7	+6	+4	+1	-2	-5	-8
12	+21	+24	+34	+40	+42	+41	+38	+33	+28	+24	+20	+18	+15	+13	+12	+10	+8	+6	+4	+1	-2
10	+21	+25	+35	+42	+44	+44	+41	+37	+32	+28	+24	+21	+19	+17	+16	+14	+12	+10	+7	+5	+2
8	+22	+26	+36	+43	+46	+46	+43	+39	+35	+31	+27	+24	+21	+19	+17	+15	+12	+10	+7	+5	+3
6	+23	+27	+37	+45	+48	+47	+44	+40	+36	+31	+27	+23	+20	+17	+14	+11	+8	+5	+2	-1	-4
4	+23	+28	+38	+45	+48	+47	+44	+39	+34	+28	+23	+18	+14	+10	+5	+1	-3	-8	-12	-16	-19
2	+24	+28	+37	+44	+46	+44	+40	+34	+27	+20	+14	+7	+1	-6	-12	-18	-25	-31	-38	-44	-48
0	+24	+27	+35	+40	+41	+38	+32	+24	+15	+6	-4	-13	-22	-31	-41	-50	-60	-70	-79	-88	-95
-2	+23	+24	+31	+34	+32	+26	+18	+7	-5	-18	-31	-44	-57	-71	-85	-99					

Table 7—continued

Temperature, °C	500 dbar						1000 dbar						2000 dbar					
Salinity, ppt	30	32	34	36	38	40	30	32	34	36	38	40	30	32	34	36	38	40
36																		
34																		
32	+52	+56	+60	+63	+66	+68	+53	+58	+63	+67	+72	+75	+66	+73	+81	+89	+96	
30	+31	+34	+36	+38	+39	+39	+30	+34	+37	+40	+42	+44	+40	+46	+52	+58	+64	+69
28	+15	+16	+17	+18	+17	+16	+13	+15	+17	+19	+20	+20	+21	+25	+30	+35	+39	+43
26	+3	+3	+3	+3	+2	+0	+0	+1	+2	+3	+3	+3	+6	+10	+14	+18	+22	+25
24	−5	−6	−6	−7	−9	−11	−9	−9	−8	−8	−8	−9	−4	+0	+3	+7	+10	+13
22	−10	−11	−12	−13	−15	−17	−14	−14	−14	−14	−14	−15	−9	−6	−2	+1	+4	+7
20	−12	−12	−13	−15	−17	−19	−16	−16	−16	−16	−16	−17	−11	−8	−4	+0	+4	+7
18	−11	−11	−12	−14	−16	−18	−16	−15	−15	−14	−14	−15	−10	−6	−2	+2	+7	+11
16	−8	−9	−9	−10	−12	−14	−13	−12	−11	−11	−10	−10	−7	−2	+2	+7	+12	+18
14	−4	−5	−5	−6	−7	−8	−9	−8	−7	−6	−5	−4	−2	+2	+8	+14	+20	+26
12	+0	−1	−1	−2	−2	−3	−6	−4	−3	−2	+0	+2	+2	+7	+13	+20	+27	+34
10	+2	+2	+1	+1	+0	+0	−3	−2	+0	+1	+3	+5	+5	+11	+17	+25	+32	+41
8	+2	+2	+1	+0	+0	−1	−4	−3	−1	+1	+3	+5	+4	+11	+18	+25	+34	+43
6	−2	−4	−5	−6	−7	−8	−9	−9	−7	−6	−4	−2	−1	+5	+12	+20	+28	+38
4	−13	−16	−18	−21	−23	−24	−21	−22	−22	−21	−21	−19	−14	−9	−3	+4	+13	+22
2	−33	−38	−43	−47	−51	−54	−43	−45	−47	−49	−50	−49	−37	−34	−29	−24	−17	−8
0	−66	−74	−82	−89	−96		−78	−83	−88	−93	−96	−99	−75	−74	−72	−69	−64	−58
−2																		
−4																		

Salinity, ppt

Salinity, ppt	16 °C	20 °C	24 °C
42	−11	−11	−12
40	−7	−8	−7
38	−4	−4	−4
36	−1	−1	−1
34	+1	+1	+1
32	+3	+3	+2
30	+5	+4	+3
28	+6	+5	+4
26	+8	+7	+6
24	+10	+9	+8
22	+14	+12	+12
20	+18	+16	+16
18	+22	+21	+21
16	+28	+27	+27
14	+33	+32	+33
12	+37	+37	+38
10	+39	+39	+40
8	+37	+38	+39
6	+32	+32	+34
4	+23	+23	+25
2	+20	+20	+21

°C

ΔG_B

See footnote to Table 3.

Table 8. Conversion of sample profile from RIBE *and* HOWE (1975) *to PSS* 1978

				$(S'-S)‰ \times 10^3$	
Pressure (dbar)	T_{68} °C	Salinity (‰)	$\Delta F ‰ \times 10^3$	ΔK Method	ΔS Method
0	10.470	32.610	4.2	3.7	3.7
20	9.810	32.620	4.6	4.1	4.1
30	8.480	32.650	5.6	5.1	5.1
50	6.480	32.700	6.4	5.9	5.9
75	5.300	32.740	6.5	6.0	6.0
100	4.730	32.790	6.5	6.0	6.0
500	3.590	34.120	3.1	2.6	2.6
1000	2.850	34.390	1.1	0.6	0.6
2000	1.960	34.590	−0.5	−1.0	−1.0
4000	1.520	34.680	−1.2	−1.7	−1.7

The bottle sample was collected at 1000 m and analysed at 16°C to give the 34.39‰ value. From Table 6 (RIBE and HOWE) $\Delta G_B = 0.6$, ΔF_B (1000 dbar) $= 1.1$ to give $(1 - K'/K) = 1.3 \times 10^{-5}$ (refer to equation 9).

In this case, the ΔK and ΔS methods differ by 0.003 salinity. Now using (9), (10) can be rewritten; $S' - S = \Delta F - (1 - K'/K)(a S_B + b S_B^2)$ and comparison with (8) shows that it is the difference between S and S_B that has allowed the results of the two methods to be different. It is also clear that if bS^2 is neglected with respect to aS that a ΔS correction proportional to S would be better than the commonly used simple additive constant.

Table 8 shows the conversion from RIBE and HOWE (1975) of a sample profile taken at Ocean Station P in the North Pacific, 50°N, 145°W (July means). In this case the small range of salinity values results in identical ΔK and ΔS corrections.

RECOMMENDATIONS FOR DATA CONVERSION

From the above tables and examples it can be seen that much previously archived data in the oceanic range of salinities (33 to 37‰) will be within ±0.01‰ of salinity computed by the PSS 78 from the same measurements. LEWIS and PERKIN (1978) have estimated that ±0.01 is near the limit of accuracy achievable by the present CTD machines but the resulting profile is often calibrated to closer limits by single or multiple bottle sample analyses. Alternatively, many deep-sea oceanographers have used historical values as fixed points through which their measured profiles must pass. A typical salinity profile with an accuracy in salinity of ±0.01, precision ±0.003, and resolution of ±0.002 is 'pegged' by assuming the historical value at, say, 4000 m, is 'correct'. This means that the archived data will be assumed to be 'accurate' to within 0.002. Over the years the relationship between salinity and potential temperature for abyssal waters has been the same within experimental error [e.g., REED (1969) for the Pacific]. If this is true at the measurement site then an *in situ* instrument can be calibrated accurately, at depth, simply by measuring the temperature and pressure and referring to the historical relationship for salinity. The continuing analysis of bottle samples serves to show any trend in the historical values.

MONTGOMERY (1958) gave the characteristics of world oceanic water and showed that 99% of the water lies within a salinity range of 33 to 37. The change in salinity on conversion to the new scale for this salinity range can be found by reference to Table 2 and, over the normal range of laboratory temperatures used for bottle sample analysis, the change is very small. Therefore, for practical purposes, historical values will be preserved under the new scale. This is not necessarily the case for historical salinities derived from chlorinity because, as noted by Cox *et al.* (1967) the chlorinity-conductivity relationship varies as a function of depth and geographic location.

The use of historical values for calibration, although convenient, cannot be recommended over the procedure of bottle sample collection and analysis. There is some evidence that in addition to trends, unexpected temperatures (WONG, 1972) and salinities (FOFONOFF and TABATA, 1966) may occasionally appear even at great depth. Thus historical values, although providing a useful check, are no substitute for bottle samples in CTD calibrations.

If a decision should be made to convert large data files to their PSS 78 values, two approaches are recommended. The first and most direct is to gain access to the raw data and re-compute everything using PSS 78. If this can be accomplished without too much labour, it is the most desirable because it involves no approximation. The second recommended method is to enter the pertinent parts of the tables published in this paper and to interpolate the values of ΔG and ΔF needed for the ΔK or ΔS methods described above. Second-degree interpolation is recommended for rapidly changing parts of the tables. The advantage of the second method is that knowledge of the raw conductivity data is not necessary because the old salinity can be used to look up tabulated values. Bottle samples analysed on a bench salinometer can be corrected by the columns on the lower right of the various tables (ΔG_B) or by Table 2 if the International Tables were used to compute salinity. Note that the differences listed on Table 2 are almost independent of the temperature at which the bottle samples were analysed so that, for many cases, the correction could be made adequately from knowledge of the salinity alone. If enough bottle samples were used to correct the original profile, then conversion to PSS 78 could be accomplished merely by adjusting the original profile over by the amount by which the bottles had been changed. Obviously, each case would have to be examined to determine the errors involved in the simplification.

Variations in the chlorinity–conductivity relationship make it impossible to do a true conversion from chlorinity values into the PSS 78. Nevertheless, on occasions it may be necessary to attempt comparisons between data collected by the two techniques. The problem is best tackled by using the old relationship between chlorinity and salinity ($S = 1.80655$ Cl) to obtain a salinity and then using the International Tables (UNESCO, 1966) which are based on 'average' seawater, to obtain a value of R_{15}. This value can then be used as K_{15} in equation (1) of the Appendix to obtain a practical salinity. Alternately, the R_{15} value can be used in new oceanographic tables of practical salinity as a function of conductivity ratio, to be published by UNESCO shortly. It must be emphasized that the conversion procedure is improper in terms of the definition of the PSS 78 and is offered here only as a best solution. Practical salinities so derived have uncertain errors though normally they are unlikely to exceed ± 0.03. Although uncertainties due to variations in ionic content remain it is worth noting that salinities computed from chlorinity by the Knudsen equation ($S = 0.03 + 1.805$ Cl) are in much better agreement with the new scale. Differences are reduced to within ± 0.001 over the range $25 < S < 38$ provided the water studied has a composition that can be described properly by the original chlorinity–conductivity relationship of Cox *et al.* (1967) on which the International Tables are based.

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REFERENCES

BENNETT A. S. (1976) Conversion of *in situ* measurements of conductivity to salinity. *Deep-Sea Research*, **23**, 157–165.

BRADSHAW A. and K. E. SCHLEICHER (1965) The effect of pressure on the electrical conductance of sea water. *Deep-Sea Research*, **12**, 151–162.

BROWN N. L. and B. ALLENTOFT (1966) Salinity, conductivity and temperature relationship of sea water over the range 0–50 ppt. Final report March 1, prepared for the United States Office of Naval Research, Contract No. 4290 (00). M.J.O. No. 2003 (Unpublished document).

COX R. A., F. CULKIN and J. P. RILEY (1967) The electrical conductivity/chlorinity relationship in natural sea water. *Deep-Sea Research*, **14**, 203–220.

FEDOROV K. N. (1971) Formulas for converting the electrical conductivity of sea water into salinity with a digital temperature–salinity probe under average ocean conditions. *Oceanology*, **11**, 622–626.

FOFONOFF N. P., S. P. HAYES and R. C. MILLARD, JR. (1974) WHOI/Brown CTD microprofiler: Methods of calibration and data handling, Report WHOI–74–89, 64 pp., Woods Hole Oceanographic Institution, Woods Hole, Massachusetts (Unpublished document).

FOFONOFF N. P. and S. TABATA (1966) Variability of oceanographic conditions between Ocean Station P and Swiftsure Bank of the Pacific Coast of Canada. *Journal of the Fisheries Research Board of Canada*, **23**, 825–868.

LEWIS E. L. (1980) The Practical Salinity Scale 1978 and its antecedents. *Journal of Oceanic Engineering*, **5**(1), 3–8.

LEWIS E. L. and R. G. PERKIN (1978) Salinity: its definition and calculation. *Journal of Geophysical Research*, **83**(C1), 466–478.

MONTGOMERY R. B. (1958) Water characteristics of Atlantic Ocean and of world ocean. *Deep-Sea Research*, **5**, 134–148.

PERKIN R. G. and E. R. WALKER (1972) Salinity calculations from in situ measurements. *Journal of Geophysical Research*, **77**, 6618–6621.

POISSON A., T. DAUPHINEE, C. K. ROSS and F. CULKIN (1978) The reliability of standard seawater as an electrical conductivity standard. *Oceanologica Acta*, **1**, 425–433.

REED R. K. (1969) Deep water properties and flow in the central North Pacific. *Journal of Marine Research*, **27**, 24–31.

RIBE R. L. and J. G. HOWE (1975) An empirical equation relating seawater salinity, temperature, pressure and electrical conductivity. *Marine Technology Society Journal*, **9**, 3–13.

UNESCO (1966) Table 1, in *International Oceanographic Tables*. National Institute of Oceanography of Great Britain and UNESCO, Paris.

WONG C. S. (1972) Deep zonal water masses in the equatorial Pacific Ocean inferred from anomalous oceanographic properties. *Journal of Geophysical Research*, **77**, 7196–7202.

APPENDIX

Definition of the Practical Salinity Scale 1978

(1) Absolute salinity, symbol S_A, is defined as the ratio of mass of dissolved material in seawater to the mass of seawater. In practice this quantity cannot be measured directly and a practical salinity is defined for reporting oceanographic observations.

(2) The practical salinity, symbol S, of a sample of seawater, is defined in terms of the ratio K_{15} of the electrical conductivity of the seawater sample at the temperature of 15°C and the pressure of one standard atmosphere, to that of a potassium chloride (KCl) solution, in which the mass fraction of KCl is 32.4356×10^{-3}, at the same temperature and pressure. The K_{15} value exactly equal to 1 corresponds, by definition, to a practical salinity exactly equal to 35. The practical salinity is defined in terms of the ratio K_{15} by the following equation:

$$S = a_0 + a_1 K_{15}^{1/2} + a_2 K_{15} + a_3 K_{15}^{3/2} + a_4 K_{15}^2 + a_5 K_{15}^{5/2}, \tag{1}$$

$$\begin{aligned} a_0 &= 0.0080 \\ a_1 &= -0.1692 \\ a_2 &= 25.3851 \\ a_3 &= 14.0941 \\ a_4 &= -7.0261 \\ a_5 &= 2.7081 \\ \sum a_i &= 35.0000 \\ 2 \leqslant S &\leqslant 42. \end{aligned}$$

As a consequence of this definition any oceanic water having a precisely known conductivity ratio of near unity at 15°C with the KCl solution is a secondary standard for routine calibration of oceanographic instruments. All seawaters having the same conductivity ratio have the same practical salinity. Chlorinity is to be regarded as a separate, independent variable in describing the properties of seawater. It should be noted that the Practical Salinity values are 1000 times the values of the salinity of the same samples of seawater obtained on the previous scales. For instance, a sample of seawater having a salinity of 0.03512 (i.e., 35.12‰) will have a practical salinity of 35.12.

Algorithm for in situ *data*

Given *in situ* measurements of conductivity ratio

$$R = \frac{C(S, T_{68}, p)}{C(35, 15_{68}, p)},$$

temperature T_{68} °C, and pressure p dbar, R_T can be computed as follows:

$$R_T = \frac{R}{r_T R_p}.$$

$$R_p = (1 + \alpha),$$

where

$$\alpha = \frac{A_1 p + A_2 p^2 + A_3 p^3}{1 + B_1 T + B_2 T^2 + B_3 R + B_4 TR} \tag{2}$$

and

$$\begin{aligned} A_1 &= 2.070 \times 10^{-5} \\ A_2 &= -6.370 \times 10^{-10} \\ A_3 &= 3.989 \times 10^{-15} \\ B_1 &= 3.426 \times 10^{-2} \\ B_2 &= 4.464 \times 10^{-4} \\ B_3 &= 4.215 \times 10^{-1} \\ B_4 &= -3.107 \times 10^{-3} \end{aligned}$$

$$r_T = c_0 + c_1 T + c_2 T^2 + c_3 T^3 + c_4 T^4 \tag{3}$$

$$\begin{aligned} c_0 &= 6.766097 \times 10^{-1} \\ c_1 &= 2.00564 \times 10^{-2} \\ c_2 &= 1.104259 \times 10^{-4} \\ c_3 &= -6.9698 \times 10^{-7} \\ c_4 &= 1.0031 \times 10^{-9}. \end{aligned}$$

Note that the value for c_3 was given incorrectly as -6.9689 in Lewis (1980).

Salinity can be calculated from R_T and T by the following polynomials:

$$S = a_0 + a_1 R_T^{1/2} + a_2 R_T + a_3 R_T^{3/2} + a_4 R_T^2 + a_5 R_T^{5/2} + \frac{(T-15)}{1+k(T-15)} \{b_0 + b_1 R_T^{1/2} + b_2 R_T + b_3 R_T^{3/2} + b_4 R_T^2 + b_5 R_T^{5/2}\}, \quad (4)$$

where the values of a_i have been given below equation (1) in this appendix and

$b_0 = 0.0005$ $k = 0.0162$

$b_1 = -0.0056$

$b_2 = -0.0066$

$b_3 = -0.0375$

$b_4 = 0.0636$

$b_5 = -0.0144$

$\sum b_i = 0.0000.$

Ranges of validity

$2 \leqslant S \leqslant 42$

$-2°C \leqslant T \leqslant 35°C$

$0 \leqslant p \leqslant 10{,}000$ dbar for all deep ocean waters.

For bench salinometer use, the last equation can be used alone, though it is to be noted that R_T is then a measured value, R_T.