

Getting started with the Gibbs SeaWater (GSW) Oceanographic Toolbox of TEOS-10

Notes made 4th October 2010

The International Thermodynamic Equation of Seawater – 2010 (TEOS-10) allows all the thermodynamic properties of pure water, ice Ih, seawater and moist air to be evaluated in an internally self-consistent manner. Ice Ih is the naturally abundant form of ice, having hexagonal crystals. For the first time the effects of the small variations in seawater composition around the world ocean can be included, especially their effects on the density of seawater (which can be equivalent to ten times the precision of our Practical Salinity measurements at sea).

The GSW computer software toolbox contains only code for the properties of seawater; the TEOS-10 software for evaluating the properties of ice Ih and of humid air is available in the SIA (Seawater-Ice-Air) software library from <http://www.TEOS-10.org>

TEOS-10 has introduced several new variables into oceanography, including Absolute Salinity S_A , Preformed Salinity S_* , and Conservative Temperature Θ . These variables are introduced below, and then the use of these variables is discussed, followed by the complete listing and description of the functions available in the GSW toolbox. These notes end with the recommendations of SCOR/IAPSO Working Group 127, as endorsed by the Intergovernmental Oceanographic Commission, for the nomenclature, symbols and units to be used in physical oceanography, repeated from appendix L of IOC *et al.* (2010).

Installing the GSW Oceanographic Toolbox

1. Download the GSW Oceanographic Toolbox,
2. Unzip the Toolbox to a directory you name "GSW" (ensuring that the subdirectories have also been extracted).

Then, in MATLAB

3. Add the "GSW" directory to your MATLAB path using "Add with subfolders" (i. e. "File" → "Set Path..."), or using the "addpath" command.

**ENSURE THAT ALL THE SUBFOLDERS (i.e. html, library, pdf)
HAVE BEEN ADDED TO THE PATH.**

4. Run **gsw_check_functions** to check that the Toolbox is correctly installed and that there are no conflicts. (This function runs three stored vertical profiles through all of the GSW functions, and checks that the outputs are within pre-defined limits of the correct values. These pre-defined limits are a factor of approximately a hundred larger than the errors expected from the numerical precision of different computers, at the standard double precision of MATLAB).

If the MATLAB Desktop is running,

5. Run **gsw_introduction** to gain access to the front page of the GSW Oceanographic Toolbox, which describes all aspects of the Toolbox.

Having installed the GSW Oceanographic Toolbox, the command **gsw_contents** will show the contents list of the software functions. The software descriptions and the help files for these functions can be accessed by clicking on the function names on this list.

A user may want to run **gsw_check_functions** periodically to confirm that the software remains uncorrupted.

Absolute Salinity S_A

Perhaps the most apparent change in using TEOS-10 compared with using the International Equation of State of seawater (EOS-80) is the adoption of Absolute Salinity S_A instead of Practical Salinity S_p (PSS-78) as the salinity argument for the thermodynamic properties of seawater. Importantly, Practical Salinity is retained as the salinity variable that is stored in databases because Practical Salinity. This is done to maintain continuity in the archived salinity variable, and also because Practical Salinity is virtually the measured variable (whereas Absolute Salinity is a calculated variable).

Absolute Salinity is calculated in a two-stage process. First, Reference Salinity S_R (Millero *et al.* (2008)) is calculated from Practical Salinity using the equation

$$S_R = \left(\frac{35.165\,04\,\text{g kg}^{-1}}{35} \right) S_p . \quad (1)$$

For Standard Seawater, Reference Salinity is equal to Absolute Salinity. For seawater of non-standard composition, Absolute Salinity is not proportional to Practical Salinity. To include the effects of composition variations on the absolute salinity (mass fraction) of seawater, Reference Salinity is first calculated and then the Absolute Salinity Anomaly δS_A is estimated from the computer algorithm of McDougall *et al.* (2010a), or by other means. Absolute Salinity is then formed by summing Reference Salinity and Absolute Salinity Anomaly. The GSW algorithm for calculating Absolute Salinity from Practical Salinity, **gsw_SA_from_SP**(S_p , p , long, lat), takes the form (McDougall *et al.* (2010a))

$$S_A = S_R + \delta S_A = \left(\frac{35.165\,04\,\text{g kg}^{-1}}{35} \right) S_p + \delta S_A(p, \lambda, \phi) = S_A(S_p, p, \lambda, \phi), \text{ Non-Baltic} \quad (2)$$

where p is sea pressure, λ is longitude (degrees east, ranging from 0°E to 360°E) while ϕ is latitude (degrees North), and the Absolute Salinity Anomaly δS_A is obtained from the **gsw_delta_SA** algorithm of McDougall *et al.* (2010a). If the function detects that the location is in the Baltic Sea, Absolute Salinity S_A is calculated according to $S_A - S_R = 0.087\,\text{g kg}^{-1} \times (1 - S_p/35)$ (from Eqn. (A.5.6) of IOC *et al.* (2010), following Feistel *et al.* (2010)), so that

$$S_A = \frac{(35.165\,04 - 0.087)\,\text{g kg}^{-1}}{35} S_p + 0.087\,\text{g kg}^{-1}. \quad \text{Baltic Sea} \quad (3)$$

In summary, the **gsw_SA_from_SP** function returns either Eqn. (2) or Eqn. (3) depending on whether the observation is outside or inside the Baltic Sea.

The largest influence of the variable seawater composition occurs in the northern North Pacific where $S_A - S_R = \delta S_A$ is as large as $0.027\,\text{g kg}^{-1}$ (see Figure 2 of IOC *et al.* (2010) which is reproduced below), this being the difference between Absolute Salinity and the estimate of Absolute Salinity which can be made on the basis of Practical Salinity alone. This increment of salinity equates to an increment of density of approximately $0.020\,\text{kg m}^{-3}$.

In order to gauge the importance of the spatial variation of seawater composition, the northward gradient of density at constant pressure is shown in Fig. A.5.1 of IOC *et al.* (2010) (and this figure is reproduced below) for the data in a world ocean hydrographic atlas deeper than 1000m. The vertical axis in this figure is the magnitude of the difference between the northward density gradient at constant pressure when the TEOS-10 algorithm for density is called with S_A (as it should be) compared with calling the same TEOS-10 density algorithm with S_R as the salinity argument. Figure A.5.1 shows that the “thermal wind” is misestimated by more than 2% for 58% of the data in the world ocean below a depth of 1000m if the effects of the variable seawater composition are ignored. The percentage error is larger in the Pacific Ocean.

The first version of **gsw_SA_from_SP** was made available in early 2009 (then called **gsw_ASAL**). This second version (version 2) is being released in October 2010 and supersedes version 1.

Preformed Salinity S_*

Absolute Salinity S_A , Reference Salinity S_R and Practical Salinity S_p are all conservative salinity variables under the processes of (i) adiabatic pressure changes, and (ii) turbulent mixing, but none of these three salinity variables are conservative in the presence of (iii) biogeochemical processes. Preformed Salinity S_* is designed to be a conservative salinity variable which is unaffected by biogeochemical activity in the ocean; it is defined as Absolute Salinity less the contributions of biogeochemical processes to Absolute Salinity.

The **gsw_Sstar_from_SP**(SP, p, long, lat) function first finds the Absolute Salinity Anomaly δS_A using the **gsw_delta_SA** function and then uses this value to calculate Preformed Salinity S_* according to

$$S_* = \frac{35.165\,04\,\text{g kg}^{-1}}{35} S_p - r_1 \delta S_A, \quad \text{Non-Baltic} \quad (4)$$

where r_1 is taken to be the constant 0.35 based on the work of Pawlowicz *et al.* (2010). The first part of this expression, $(35.165\,04\,\text{g kg}^{-1}/35) S_p$, is the Reference Salinity S_R , which is the best estimate of Absolute Salinity for a sample of Standard Seawater.

In the Baltic Sea the deviations of Absolute Salinity from Reference Salinity are not primarily due to non-conservative biogeochemical processes but rather are due to the anomalous composition entering the Baltic from rivers. Since these anomalous constituents are conservative, Preformed Salinity S_* in the Baltic Sea is taken to be Absolute Salinity S_A . If the function detects that the location is in the Baltic Sea, Preformed Salinity S_* is calculated according to $S_A - S_R = 0.087\,\text{g kg}^{-1} \times (1 - S_p/35)$ (from Eqn. (A.5.6) of IOC *et al.* (2010), following Feistel *et al.* (2010)), so that

$$S_* = S_A = \frac{(35.165\,04 - 0.087)\,\text{g kg}^{-1}}{35} S_p + 0.087\,\text{g kg}^{-1}. \quad \text{Baltic Sea} \quad (5)$$

In summary, the **gsw_Sstar_from_SP** function returns either Eqn. (4) or Eqn. (5) depending on whether the observation is outside or inside the Baltic Sea.

The largest influence of the variable seawater composition occurs in the northern North Pacific where $S_R - S_*$ is almost $0.01\,\text{g kg}^{-1}$, and the difference between Absolute Salinity and the conservative Preformed Salinity, $S_A - S_*$, is as large as $0.036\,\text{g kg}^{-1}$. This increment of salinity equates to an increment of density of approximately $0.028\,\text{kg m}^{-3}$.

Continuing to concentrate on the mid-depth northern North Pacific, recall that the salinity difference $S_A - S_R = \delta S_A$ of $0.027\,\text{g kg}^{-1}$ represents the difference between Absolute Salinity and the estimate of it using only Practical Salinity, while the value of $S_A - S_*$ of $0.036\,\text{g kg}^{-1}$ is the total influence of biogeochemical processes on Absolute Salinity. An ocean model which treats its salinity variable as being conservative needs to account for this salinity difference, $S_A - S_*$, before density and the “thermal wind” can be accurately calculated. The reason why the salinity differences $S_A - S_R$ and $S_A - S_*$ are not equal is that biogeochemical processes have an effect on the conductivity of seawater and therefore on Practical Salinity and Reference Salinity.

Conservative Temperature Θ

Because the TEOS-10 properties of seawater are all derived from a Gibbs function, it is possible to find thermodynamic properties such as enthalpy, internal energy and entropy. Hence potential enthalpy and Conservative Temperature (which is simply proportional to potential enthalpy) are readily available.

Conservative Temperature is in some respects quite similar to potential temperature in that the same artificial thought experiment is involved with their definitions. In both cases one takes a seawater sample at an arbitrary pressure in the ocean and one imagines decreasing the pressure on the seawater parcel in an adiabatic and isohaline manner until the pressure $p = 0$ dbar is reached. The temperature of the fluid parcel at the end of this artificial thought experiment is defined to be the potential temperature θ . Similarly, the enthalpy at the end of this artificial thought experiment is defined to be its potential enthalpy h^0 , and Conservative Temperature Θ is simply potential enthalpy divided by the fixed “heat capacity” $c_p^0 \equiv 3991.867\,957\,119\,63\text{ J kg}^{-1}\text{ K}^{-1}$.

Conservative Temperature Θ represents the “heat content” of seawater much more accurately than does potential temperature θ , and Θ can be evaluated from in situ temperature t from the function **gsw_CT_from_t**. The difference between potential temperature and Conservative Temperature can be as large as $\theta - \Theta = -1.4^\circ\text{C}$ but is more typically no more than $\pm 0.1^\circ\text{C}$ (see Figure A.17.1 of IOC *et al.* (2010) which is reproduced below). Also, the parameterized lateral diffusion of “heat” along neutral tangent planes can be more than 1% different when such lateral diffusive heat fluxes are estimated using gradients of potential temperature rather than gradients of Conservative Temperature (see Figure A.14.1 of IOC *et al.* (2010) which is reproduced below).

Which type of salinity and temperature should be archived?

Since 1978 we have gone to sea and collected and then archived Practical Salinity S_p (PSS-78), in situ temperature t (now ITS-90) and pressure p at known values of longitude, latitude and time. Under TEOS-10, nothing about this data collection and storage changes. Our instruments still need to measure properly calibrated data of (S_p, t, p) at known longitude, latitude and time. These are also exactly the same data that should continue to be archived in national oceanographic archives.

In particular, it cannot be over-emphasized that NONE of Reference Salinity S_R , Absolute Salinity S_A or Preformed Salinity S_* should EVER be submitted to or stored in national oceanographic databases. This strong recommendation resonates with present practice regarding temperature; we archive the measured quantity, in situ temperature t , not the calculated quantity, potential temperature θ . Similarly, just as potential temperature is not stored in national databases, so too Conservative Temperature should not be submitted to or stored in such national databases. In short, such databases should store measured (not calculated) quantities, and for this purpose, Practical Salinity is regarded as a measured quantity.

How should the new variables S_A , S_* and Θ be used?

For the past thirty years we have taken the “raw” data of Practical Salinity S_p (PSS-78), in situ temperature t (now ITS-90) and pressure p and we have used an algorithm to calculate potential temperature θ before analyzing and publishing water-mass characteristics on the $S_p - \theta$ diagram. On this $S_p - \theta$ diagram we have been able to draw curved contours of potential density using EOS-80.

Under TEOS-10 this practice has now changed. Density and potential density (and all types of geostrophic streamfunction including dynamic height anomaly) are now not functions of Practical Salinity S_p but rather are functions of Absolute Salinity S_A . Hence it is now not possible to draw isolines of potential density on a $S_p - \theta$ diagram. Rather, because of the spatial variations of seawater composition, a given value of potential density defines an area on the $S_p - \theta$ diagram, not a curved line.

Also, under TEOS-10 there seems to be no reason to continue to use potential temperature θ as the temperature variable with which to analyze water-mass characteristics because Conservative Temperature Θ has the advantage of more accurately representing the “heat content” of seawater than does θ , and Θ is also much closer to being a 100% conservative variable than is potential temperature.

Hence, for the analysis and publication of oceanic water masses under TEOS-10 we need to change from using the $S_p - \theta$ diagram which was appropriate under EOS-80, to using the $S_A - \Theta$ diagram. It is on this $S_A - \Theta$ diagram that the isolines of potential density can be drawn under TEOS-10.

There is an extra operational step involved in the calculation of Absolute Salinity S_A from the observed data; EOS-80 did not have a corresponding step. This step of calculating Absolute Salinity S_A is perhaps the most fundamental step involved with implementing TEOS-10 as none of the other software can be called before S_A is known. If however, one did wish to ignore the spatial variations of seawater composition, then Reference Salinity S_R could be calculated from Practical Salinity (these salinities are proportional to each other), and the GSW software could then be called with S_R in place of S_A as the input salinity variable to each of the GSW functions.

Operationally, the calculation of Conservative Temperature Θ as a function of (S_A, t, p) under TEOS-10 is no different in principle from the way we used to calculate potential temperature from (S_p, t, p) under EOS-80; in both cases a simple computer algorithm is called.

What then is the appropriate use of Preformed Salinity S_* ? This salinity variable is the one which can be treated as being conservative. Hence, in contrast to the evolution equation of Absolute Salinity S_A , the evolution equation for Preformed Salinity S_* does not contain non-conservative source terms caused by biogeochemistry (see appendix A.20 of IOC *et al.* (2010)). This means that Preformed Salinity S_* is ideal for use as

- (i) the salinity variable that is advected and diffused in forward ocean models,
- (ii) the salinity variable that is advected and diffused in inverse ocean models, and
- (iii) the salinity variable that is averaged when forming a hydrographic atlas.

In these applications, the salinity difference $S_A - S_*$ is added to the averaged atlas or model salinity variable to form Absolute Salinity S_A before other thermodynamic properties (such as density etc.) are calculated. Because of its conservative nature, there is an argument that suggests that Preformed Salinity S_* should be used in place of Absolute Salinity S_A as the salinity axis of the $S_A - \Theta$ diagram, since water masses are notionally mixed on this diagram. However, to do so would take away the ability to draw isolines of potential density on this diagram, so the $S_A - \Theta$ diagram (as opposed to the $S_* - \Theta$ diagram) is recommended for water-mass analysis.

In summary, under EOS-80 we have to date used the observed variables (S_p, t, p) to first form potential temperature θ and then we have analyzed water masses on the $S_p - \theta$

diagram, and we have been able to draw curved contours of potential density on this same $S_p - \theta$ diagram. Under TEOS-10, the observed variables (S_p, t, p) , together with longitude and latitude, are used to first form Absolute Salinity S_A , and then Conservative Temperature Θ is calculated. Oceanographic water masses are then analyzed on the $S_A - \Theta$ diagram, and potential density contours can also be drawn on this $S_A - \Theta$ diagram. Preformed Salinity S_* is the natural salinity variable to be used in applications such as numerical modelling where it is important that the salinity variable be conservative.

A guide to the GSW Oceanographic Toolbox

The key attributes of the three new oceanographic variables S_A , S_* and Θ may be summarized as follows. Preformed Salinity S_* and Conservative Temperature Θ are the ideal variables for representing the “salt content” and “heat content” of seawater in the standard conservation equations of physical oceanography. However, the thermodynamic properties of seawater (in particular, density) depend not on Preformed Salinity S_* , but rather on Absolute Salinity S_A . Also, while Practical Salinity S_p is relatively easy to measure accurately, it should now be regarded as a stepping stone on the way to calculating the two more attractive salinity variables, S_A and S_* .

The current listing of GSW functions (as well as the internal library functions) is given below. These functions are grouped under several headings of functions with similar characteristics. The first grouping delivers Absolute Salinity S_A and Preformed Salinity S_* given the Practical Salinity S_p , pressure, longitude and latitude of an observation. The function **gsw_SA_Sstar_from_SP** outputs both S_A and S_* ; if both these salinities are needed it saves computer time to call this one function rather than to call both **gsw_SA_from_SP** and **gsw_Sstar_from_SP**. Note that all of the functions which follow this first group require Absolute Salinity S_A as an input. It is then clear that when analyzing oceanic data, the very first function call must be to **gsw_SA_from_SP** (or to **gsw_SA_Sstar_from_SP**). Hence this function is the most fundamental in the GSW toolbox. This function can be avoided only by ignoring the influence of the spatial variations in seawater composition, in which case the remaining GSW functions would be called with Reference Salinity S_R (given by Eqn. (1) above) in place of S_A .

The second grouping contains just the function **gsw_CT_from_t** which returns Conservative Temperature when called with Absolute Salinity S_A , in situ temperature t and pressure p . Note again that Absolute Salinity must first be calculated before Conservative Temperature can be evaluated.

The third grouping of functions has the heading “other conversions between temperatures, salinities, pressures and height”. Some of these functions are the reverse of those in the first two groups (namely **gsw_SP_from_SA**, **gsw_SP_from_Sstar** and **gsw_t_from_CT**) while others perform familiar functions such as **gsw_pt_from_t**(S_A, t, p, p_r) which evaluates the potential temperature of the “bottle” (S_A, t, p) referenced to the pressure p_r .

The grouping “density and enthalpy, based on the 25-term expression for density” contains functions that are derived from the computationally efficient 25-term rational function for density of McDougall *et al.* (2010b) (see also appendices A.30 and K of IOC *et al.* (2010)). For values of salinity, temperature and pressure that are not too different from what is observed in the ocean, this 25-term equation of state is virtually as accurate as that derived from the full Gibbs function. Since ocean models tend to use such a computationally efficient “equation of state” it follows that the analysis of output from such ocean models should employ the same equation of state as does the forward model. The functions **gsw_enthalpy_CT25** and **gsw_enthalpy_diff_CT25** are used when

evaluating various geostrophic streamfunctions, since under isentropic and isohaline conditions, enthalpy is the pressure integral of specific volume.

The next group of three functions delivers variables which are defined in terms of the vertical gradients of Absolute Salinity S_A and Conservative Temperature Θ on an individual vertical profile, and so are inherently water column properties.

The following grouping is for calculating four different geostrophic streamfunctions. Like the previous two groupings, these functions also have Absolute Salinity S_A and Conservative Temperature Θ as the input salinity and temperature. It is important to realize that a particular geostrophic streamfunction is only accurate in the surface for which it is derived, so that dynamic height anomaly is the geostrophic streamfunction in an isobaric surface and the Montgomery function is the geostrophic streamfunction in a specific volume anomaly surface. When one is working in some type of approximately neutral surface, the Cunningham geostrophic streamfunction is more accurate than the Montgomery function, while the McDougall-Klocker geostrophic streamfunction is the most accurate (see Figures 1, 2 and 3 of McDougall and Klocker (2010)).

The next group of functions, concerned with various neutral and non-linear attributes of the seawater equation of state, returns properties such as the cabbeling coefficient and the thermobaric coefficient which are concerned with how the non-linear nature of the equation of state causes unexpected mean vertical advection in the ocean. All of the functions in this group and in the previous three groups have Absolute Salinity S_A and Conservative Temperature Θ as their input salinity and temperature, and the functions also all use the computationally efficient 25-term expression for density of McDougall *et al.* (2010b)). Since this 25-term expression is essentially as accurate as the corresponding expression based on the full TEOS-10 Gibbs function (that is, the density from both expressions lie within the experimental error of density and the Temperature of Maximum Density of laboratory data), we can be fully confident in the outputs. It is also clear that these functions are the appropriate ones to be used to analyze the output of numerical ocean models which have been run with the same 25-term expression for density.

The next group of gsw functions are headed “basic thermodynamic properties in terms of (SA, t, p)”. These functions all have Absolute Salinity S_A and in situ temperature t as the input salinity and temperature variables. All the functions in this group use the full TEOS-10 Gibbs function (rather than the 25-term approximation to density).

The next group of gsw functions are headed “basic thermodynamic properties in terms of CT and pt”. These functions have either Conservative Temperature or potential temperature as their input temperature. All the functions in this group use the full TEOS-10 Gibbs function (rather than the 25-term approximation to density).

The following group “derivatives of enthalpy, entropy, CT and pt” also use the full TEOS-10 Gibbs function and have a variety of input temperatures, appropriate to the function being differentiated. The outputs of these functions are used, for example, in evaluating the amount of non-conservative production associated with each variable when two seawater parcels are mixed.

The next group, “planet Earth properties”, deliver straightforward properties of the rotating planet on which we currently reside.

The next group, “functions for laboratory use” contains two functions. One outputs Absolute Salinity given a seawater sample’s density, in situ temperature and pressure. This function is designed to be used when the density of a seawater sample is directly measured (for example by using a vibrating beam densimeter). The other function gives potential density anomaly (with reference pressure $p_r = 0$ dbar) with the input temperature being potential temperature.

The next group of two functions are the PSS-78 routines for Practical Salinity in terms of conductivity ratio and its inverse function. The input temperature to these functions is

in situ temperature (ITS-90), and the inverse algorithm is iterated until the Practical Salinity is equal to the input value to within 10^{-10} .

The next group has three functions. The first, **gsw_introduction**, is the front page to the GSW Oceanographic Toolbox. From this front page, much of the TEOS-10 documentation is available. The function **gsw_contents** displays all the GSW functions as a list, from which the help files can be read by clicking on their function names. The function **gsw_check_functions** confirms that the GSW Oceanographic Toolbox is correctly installed and that there are no conflicts. This function runs three stored vertical profiles through of all the other functions, and checks that the outputs are within predefined limits of the correct answers. These pre-defined limits are a factor of approximately a hundred larger than the errors expected from numerical round-off (at the standard double precision of MATLAB). The user may want to run **gsw_check_functions** periodically to confirm that the software remains uncorrupted.

The group of library functions are internal functions which are not intended to be called by users. There is nothing stopping a skilled operator using these programs, but unless the user is confident, it is safer to access these library routines via one of the public functions; for example, there is little or no checking on the array sizes of the input variables in these internal library functions.

Finally the GSW Oceanographic Toolbox contains the data set **gsw_data_v2_0** which must not be tampered with.

The GSW Oceanographic Toolbox is designed to be comprehensive and to be installed in its entirety, even though relatively few of the functions may be used for routine oceanographic analyses. For example, the most basic use of the GSW Oceanographic Toolbox would begin as follows with a data set of (S_p, t, p) at known longitudes and latitudes. The first steps are to call **gsw_SA_from_SP** and **gsw_CT_from_t** to convert the data set to (S_A, Θ, p) . With the data set in this form, water masses may be analyzed accurately in the $S_A - \Theta$ diagram, and in situ density and potential density are available by calling **gsw_rho_CT** with the pressure input being the in situ sea pressure p , and the reference sea pressure p_r , respectively. Alternatively, **gsw_rho_CT25** can be called in place of **gsw_rho_CT**, so utilizing the increased computational efficiency of the 25-term expression for density in terms of S_A , Θ and p . It is advisable to use this 25-term version of density when analyzing data from an ocean model that carries this same equation of state.

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Here we present a table that shows some function names in the GSW Oceanographic Toolbox of TEOS-10 and the corresponding function names in the SeaWater Matlab Library of EOS-80, http://www.cmar.csiro.au/datacentre/ext_docs/seawater.htm.

Variable	SeaWater & ESO-80	Gibbs-SeaWater (GSW) & TEOS-10
Absolute Salinity	-	gsw_SA_from_SP(SP,p,long,lat)
Conservative Temperature	-	gsw_CT_from_t(SA,t,p)
density (i.e. in situ density)	sw_dens(SP,t,p)	gsw_rho_CT(SA,CT,p), or gsw_rho(SA,t,p), or gsw_rho_CT25(SA,CT,p)
potential density	sw_pden(SP,t,p,pr)	gsw_rho_CT(SA,CT,pr), or gsw_rho_CT25(SA,CT,pr)
potential temperature	sw_ptmp(SP,t,p,pr)	gsw_pt_from_t(SA,t,p,pr)
σ_0 , using $\theta_0 = \text{sw_ptmp}(\text{SP}, \text{t}, \text{p}, 0)$	sw_dens(SP, θ_0 , 0) – 1000 kg m ⁻³	gsw_sigma0_CT(SA,CT)
σ_2 , using $\theta_2 = \text{sw_ptmp}(\text{SP}, \text{t}, \text{p}, 2000)$	sw_dens(SP, θ_2 , 2000) – 1000 kg m ⁻³	gsw_sigma2_CT(SA,CT)
σ_4 , using $\theta_4 = \text{sw_ptmp}(\text{SP}, \text{t}, \text{p}, 4000)$	sw_dens(SP, θ_4 , 4000) – 1000 kg m ⁻³	gsw_sigma4_CT(SA,CT)
specific volume anomaly	sw_svan(SP,t,p)	gsw_specvol_anom_CT(SA,CT,p) or gsw_specvol_anom_CT25(SA,CT,p)
dynamic height anomaly	– sw_gpan(SP,t,p)	gsw_geo_strf_dyn_height(SA,CT,p,delta_p,interp_style)
geostrophic velocity	sw_gvel(ga,lat,long)	gsw_geostrophic_velocity(geo_str,long,lat,p)
N^2	sw_bfrq(SP, t, p, lat)	gsw_Nsquared_CT25(SA,CT,p,lat)
pressure from height (SW uses depth, not height)	sw_pres(– z,lat)	gsw_p_from_z(z,lat)
height from pressure (SW outputs depth, not height)	z = – sw_dpth(p,lat)	gsw_z_from_p(p,lat)
in situ temperature from pt	sw_temp(SP,pt,p,pr)	gsw_pt_from_t(SA,pt,pr,p)
sound speed	sw_svel(SP,t,p)	gsw_sound_speed(SA,t,p)
isobaric heat capacity	sw_cp(SP,t,p)	gsw_cp(SA,t,p)
adiabatic lapse rate*	sw_adtg(SP,t,p)	gsw_adiabatic_lapse_rate(SA,t,p)
SP from cndr, (PSS-78)	sw_salt(cndr,t,p)	gsw_SP_from_cndr(cndr,t,p)
cndr from SP, (PSS-78)	sw_cndr(SP,t,p)	gsw_cndr_from_SP(SP,t,p)
distance	sw_dist(lat,long,units)	gsw_distance(long,lat,p)
gravitational acceleration	sw_g(lat,z)	gsw_grav(lat,p)
Coriolis parameter	sw_f(lat)	gsw_f(lat)
testing of all functions	sw_test	gsw_check_functions
contents	Contents	gsw_contents

* The SW and GSW functions output the adiabatic lapse rate in different units, being K (dbar)⁻¹ and K Pa⁻¹ respectively.

Below is a complete listing of the functions (and the internal library functions) of the GSW MATLAB toolbox. At the end of these notes we have copied appendix L of IOC *et al.* (2010). This appendix lists the recommended nomenclature symbols and units for thermodynamic quantities for use by oceanographers. The adoption of a common nomenclature by the community will greatly aid in communication of the science.

The Gibbs SeaWater (GSW) Oceanographic Toolbox of TEOS-10

Absolute Salinity (SA) and Preformed Salinity (Sstar)

gsw_SA_from_SP	Absolute Salinity from Practical Salinity
gsw_Sstar_from_SP	Preformed Salinity from Practical Salinity
gsw_SA_Sstar_from_SP	Absolute Salinity & Preformed Salinity from Practical Salinity

Conservative Temperature (CT)

gsw_CT_from_t	Conservative Temperature from in-situ temperature
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other conversions between temperatures, salinities, pressure and height

gsw_t_from_CT	in-situ temperature from Conservative Temperature
gsw_pt_from_CT	potential temperature from Conservative Temperature
gsw_CT_from_pt	Conservative Temperature from potential temperature
gsw_pot_enthalpy_from_pt	potential enthalpy from potential temperature
gsw_pt0_from_t	potential temperature with a reference pressure of zero dbar
gsw_pt_from_t	potential temperature
gsw_SP_from_SA	Practical Salinity from Absolute Salinity
gsw_Sstar_from_SA	Preformed Salinity from Absolute Salinity
gsw_SA_from_Sstar	Absolute Salinity from Preformed Salinity
gsw_SP_from_Sstar	Practical Salinity from Preformed Salinity
gsw_z_from_p	height from pressure
gsw_p_from_z	pressure from height
gsw_t90_from_t48	ITS-90 temperature from IPTS-48 temperature
gsw_t90_from_t68	ITS-90 temperature from IPTS-68 temperature

density and enthalpy, based on the 25-term expression for density

gsw_rho_CT25	in-situ density
gsw_rho_alpha_beta_CT25	in-situ density, thermal expansion & saline contraction coefficient
gsw_specvol_CT25	specific volume
gsw_specvol_anom_CT25	specific volume anomaly
gsw_enthalpy_CT25	enthalpy
gsw_enthalpy_diff_CT25	difference of enthalpy between two pressures

water column properties, based on the 25-term expression for density

gsw_Nsquared_CT25	buoyancy (Brunt-Vaisala) frequency squared (N^2)
gsw_Turner_Rsubrho_CT25	Turner angle & Rsubrho
gsw_IPV_vs_fNsquared_ratio_CT25	ratio of the vertical gradient of potential density (with reference pressure, p_r), to the vertical gradient of locally-referenced potential density

geostrophic streamfunctions, based on the 25-term expression for density

gsw_geo_strf_dyn_height	dynamic height anomaly
gsw_geo_strf_dyn_height_pc	dynamic height anomaly for piecewise constant profiles
gsw_geo_strf_McD_Klocker	McDougall-Klocker geostrophic streamfunction
gsw_geo_strf_McD_Klocker_pc	McDougall-Klocker geostrophic streamfunction for piecewise constant profiles
gsw_geo_strf_Montgomery	Montgomery geostrophic streamfunction
gsw_geo_strf_Cunningham	Cunningham geostrophic streamfunction
gsw_geostrophic_velocity	geostrophic velocity

neutral and non-linear properties, based on the 25-term expression for density

gsw_cabbeling_CT25	cabbeling coefficient
gsw_thermobaric_CT25	thermobaric coefficient
gsw_isopycnal_slope_ratio_CT25	ratio of the slopes of isopycnals on the SA-CT diagram for p & pr
gsw_isopycnal_vs_ntp_CT_ratio_CT25	ratio of the gradient of Conservative Temperature in a potential density surface to that in the neutral tangent plane
gsw_ntp_pt_vs_CT_ratio_CT25	ratio of gradients of potential temperature & Conservative Temperature in a neutral tangent plane (i.e. in a locally-referenced potential density surface)

basic thermodynamic properties in terms of (SA, t, p)

gsw_rho	in situ density
gsw_pot_rho	potential density
gsw_specvol	specific volume
gsw_specvol_anom	specific volume anomaly
gsw_alpha_wrt_CT	thermal expansion coefficient with respect to Conservative Temperature
gsw_alpha_wrt_pt	thermal expansion coefficient with respect to potential temperature
gsw_alpha_wrt_t	thermal expansion coefficient with respect to in situ temperature
gsw_beta_const_CT	saline contraction coefficient at constant Conservative Temperature
gsw_beta_const_pt	saline contraction coefficient at constant potential temperature
gsw_beta_const_t	saline contraction coefficient at constant in situ temperature
gsw_entropy	entropy
gsw_internal_energy	internal energy
gsw_enthalpy	enthalpy
gsw_cp	isobaric heat capacity
gsw_isochoric_heat_cap	isochoric heat capacity of seawater
gsw_chem_potential_relative	relative chemical potential
gsw_chem_potential_water	chemical potential of water in seawater
gsw_chem_potential_salt	chemical potential of salt in seawater
gsw_Helmholtz_energy	Helmholtz energy
gsw_sound_speed	sound speed
gsw_kappa	isentropic compressibility
gsw_kappa_const_t	isothermal compressibility
gsw_adiabatic_lapse_rate	adiabatic lapse rate
gsw_molality	molality of seawater
gsw_ionic_strength	ionic strength of seawater
gsw_osmotic_coefficient	osmotic coefficient of seawater
gsw_temps_maxdensity	temperatures of maximum density of seawater

basic thermodynamic properties in terms of CT and pt

gsw_rho_CT	in situ density from CT
gsw_rho_alpha_beta_CT	density, thermal expansion & saline contraction coefficient from CT
gsw_specvol_CT	specific volume from CT
gsw_specvol_anom_CT	specific volume anomaly from CT
gsw_sigma0_CT	sigma_0 in terms of SA & CT with reference pressure of 0 dbar
gsw_sigma1_CT	sigma_1 in terms of SA & CT with reference pressure of 1000 dbar
gsw_sigma2_CT	sigma_2 in terms of SA & CT with reference pressure of 2000 dbar
gsw_sigma3_CT	sigma_3 in terms of SA & CT with reference pressure of 3000 dbar
gsw_sigma4_CT	sigma_4 in terms of SA & CT with reference pressure of 4000 dbar
gsw_enthalpy_CT	enthalpy from CT
gsw_enthalpy_diff_CT	difference of enthalpy from CT between two pressures
gsw_entropy_from_pt	entropy from potential temperature
gsw_entropy_from_CT	entropy from Conservative Temperature
gsw_pt_from_entropy	potential temperature from entropy
gsw_CT_from_entropy	Conservative Temperature from entropy

derivatives of enthalpy, entropy, CT and pt

gsw_CT_first_derivatives	first derivatives of Conservative Temperature
gsw_CT_second_derivatives	second derivatives of Conservative Temperature
gsw_enthalpy_first_derivatives	first derivatives of enthalpy
gsw_enthalpy_second_derivatives	second derivatives of enthalpy
gsw_entropy_first_derivatives	first derivatives of entropy
gsw_entropy_second_derivatives	second derivatives of entropy
gsw_pt_first_derivatives	first derivatives of potential temperature
gsw_pt_second_derivatives	second derivatives of potential temperature

planet Earth properties

gsw_f	Coriolis parameter (f)
gsw_grav	Gravitational acceleration
gsw_distance	spherical earth distance between points in long, lat coordinates at a given pressure

functions for laboratory use

gsw_SA_from_rho	Absolute Salinity from density measurements
gsw_sigma0_pt	sigma_0 in terms of SA & pt0 with reference pressure of 0 dbar

Practical Salinity (SP), PSS-78

gsw_SP_from_cndr	Practical Salinity from conductivity ratio
gsw_cndr_from_SP	conductivity ratio from Practical Salinity

Front page, contents and check values of the GSW Oceanographic Toolbox

gsw_introduction	front page to the GSW Oceanographic Toolbox
gsw_contents	contents of the GSW Oceanographic Toolbox
gsw_check_functions	checks that all the GSW functions work correctly

library functions of the GSW Toolbox (internal functions; not intended to be called by users)

The GSW functions above call the following library functions,

gsw_gibbs	the TEOS-10 Gibbs function and its derivatives
gsw_delta_SA	Absolute Salinity Anomaly (excluding the Baltic Sea)
gsw_SA_from_SP_Baltic	Calculates Absolute Salinity in the Baltic Sea
gsw_SP_from_SA_Baltic	Calculates Practical Salinity in the Baltic Sea
gsw_infunnel	"oceanographic funnel" check for the 25-term equation
gsw_entropy_part	entropy minus the terms that are a function of only SA
gsw_entropy_part_zerop	entropy_part evaluated at 0 dbar
gsw_interp_McD_Klocker	linearly interpolates the reference cast
gsw_interp_SA_CT	linearly interpolates (SA,CT,p) to the desired p
gsw_gibbs_pt0_pt0	gibbs(0,2,0,SA,t,0)
gsw_specvol_SSO_0_CT25	spec_vol_CT25(35.16504,0,p)
gsw_enthalpy_SSO_0_CT25	enthalpy_CT25(35.16504,0,p)

The GSW data set

gsw_data_v2_0	contains (1) the global data set of Absolute Salinity Anomaly, (2) a reference cast (for the McD_Klocker streamfunction), and (3) three vertical profiles of (SP, t, p) at known long & lat, plus the outputs of all the GSW functions for these 3 profiles, and the required accuracy of all these outputs.
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Licences and 3rd party software

gsw_licence	creative commons licence for the GSW Oceanographic Toolbox
cprintf	prints colour text to the screen (3 rd party software)
cprintf_licence	licence for cprintf software

Below are Figures 2(a) and 2(b) of IOC *et al.* (2010).

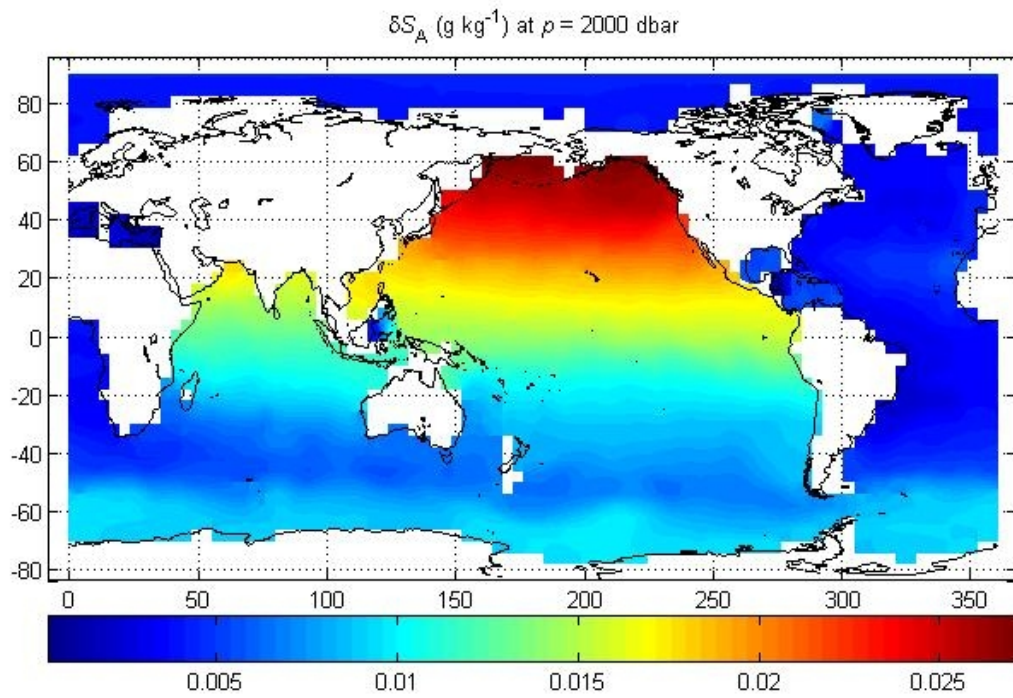


Figure 2 (a). Absolute Salinity Anomaly δS_A at $p = 2000$ dbar.

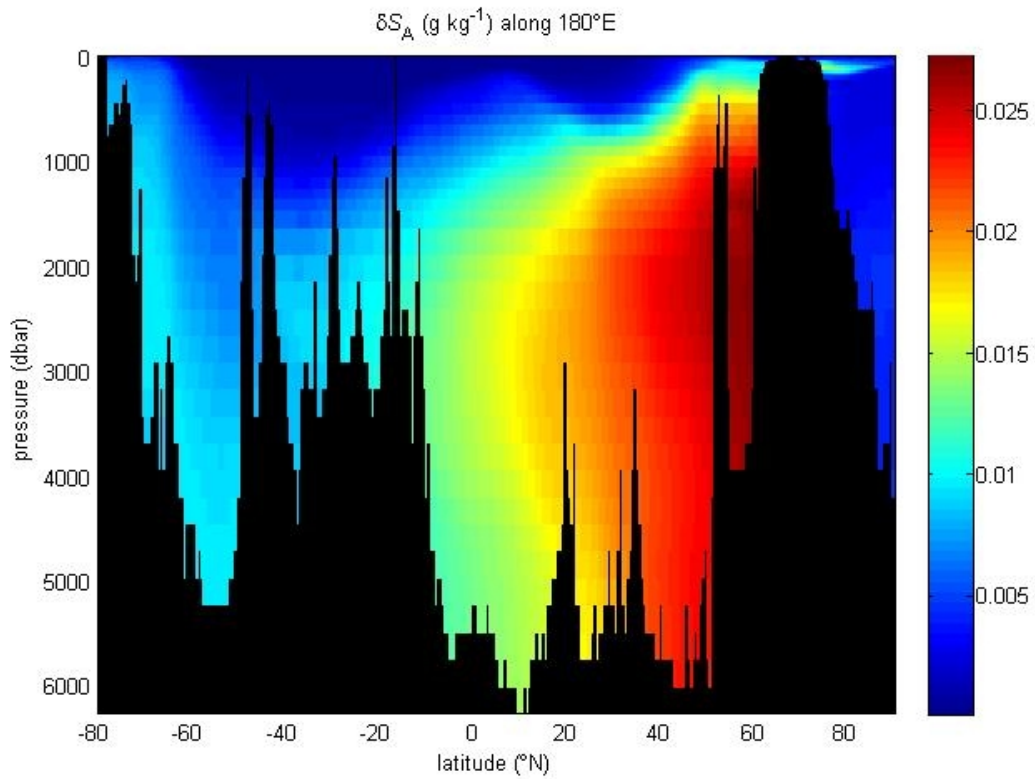


Figure 2 (b). A vertical section of Absolute Salinity Anomaly δS_A along 180°E in the Pacific Ocean.

Below is Figure A.5.1 of IOC *et al.* (2010).

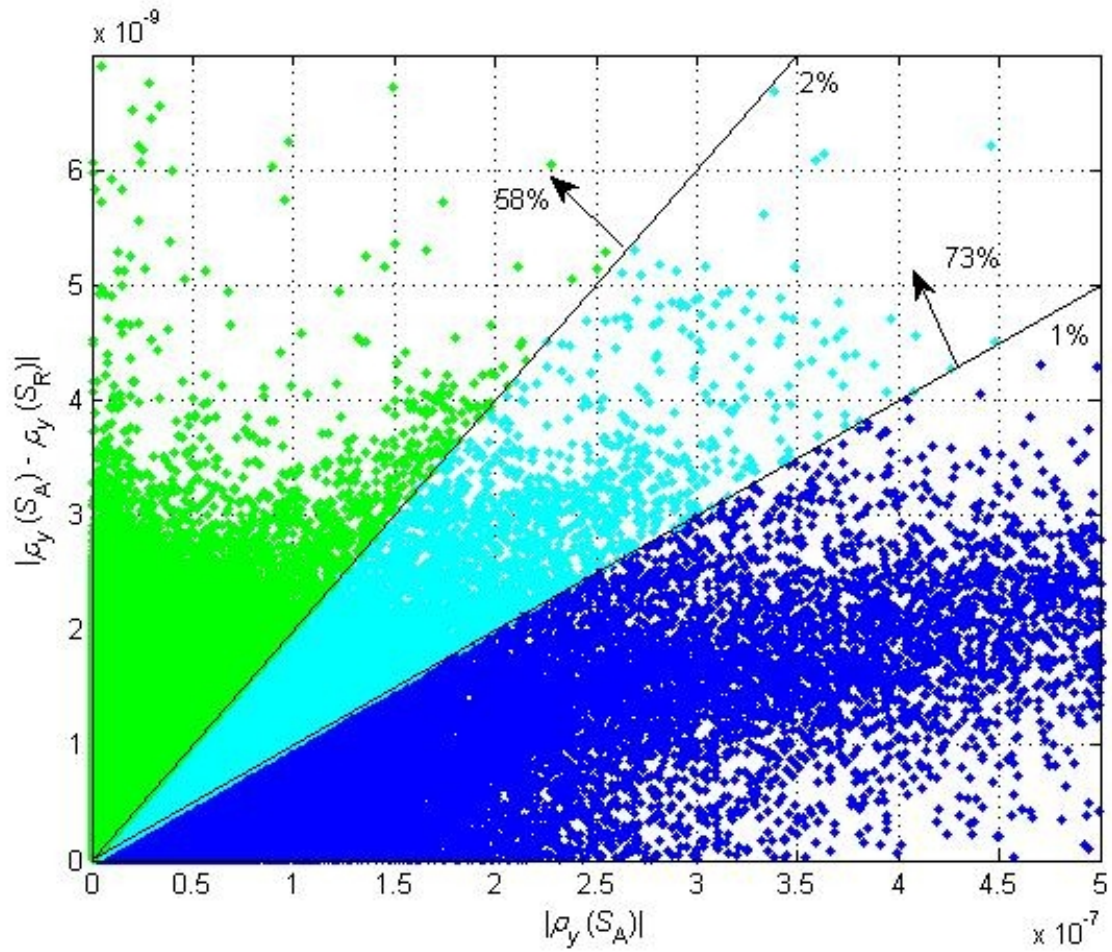


Figure A.5.1. The northward density gradient at constant pressure (the horizontal axis) for data in the global ocean atlas of Gouretski and Koltermann (2004) for $p > 1000$ dbar. The vertical axis is the magnitude of the difference between evaluating the density gradient using S_A versus S_R as the salinity argument in the TEOS-10 expression for density.

Below are Figures A.17.1 and A.14.1 of IOC *et al.* (2010).

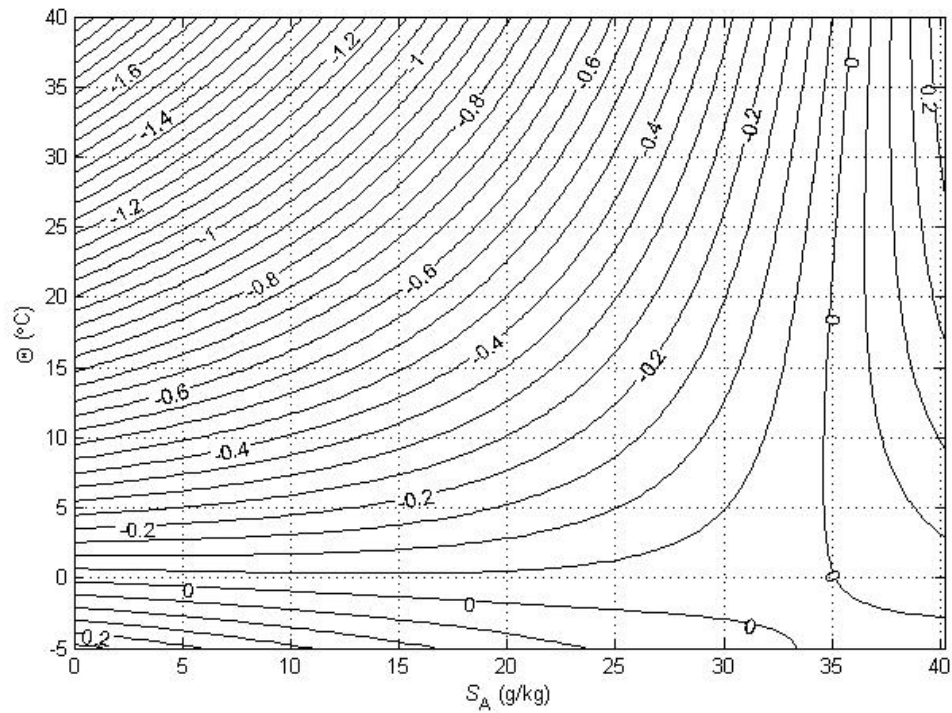


Figure A.17.1. Contours (in $^{\circ}\text{C}$) of the difference between potential temperature and Conservative Temperature $\theta - \Theta$. This plot illustrates the non-conservative production of potential temperature θ in the ocean.

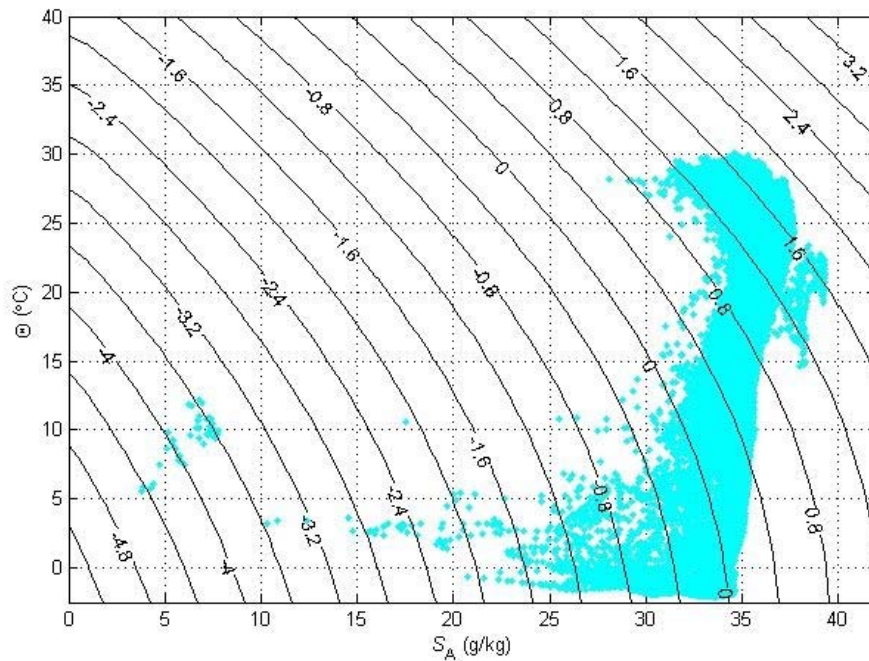


Figure A.14.1. Contours of $(|\nabla_n \theta|/|\nabla_n \Theta| - 1) \times 100\%$ at $p = 0$, showing the percentage difference between the epineutral gradients of θ and Θ . The blue dots are from the ocean atlas of Gouretski and Koltermann (2004) at $p = 0$.

Appendix L: Recommended nomenclature, symbols and units in oceanography

L.1 Recommended nomenclature

The strict SI units of Absolute Salinity, temperature and pressure are kg kg^{-1} , Absolute Temperature in K and Absolute Pressure P in Pa. These are the units predominantly adopted in the SIA computer software for the input and output variables. If oceanographers were to adopt this practice of using strictly SI quantities it would simplify many thermodynamic expressions at the cost of using unfamiliar units.

The GSW Oceanographic Toolbox (appendix N) adopts as far as possible the currently used oceanographic units, so that the input variables for all the computer algorithms are Absolute Salinity in S_A in g kg^{-1} , temperature in $^{\circ}\text{C}$ and pressure as sea pressure in dbar. The outputs of the functions are also generally consistent with this choice of units, but some variables are more naturally expressed in SI units.

It seems impractical to recommend that the field of oceanography fully adopt strict basic SI units. It is however very valuable to have the field adopt uniform symbols and units, and in the interests of achieving this uniformity we recommend the following symbols and units. These are the symbols and units we have adopted in the GSW Oceanographic Toolbox.

Table L.1. Recommended Symbols and Units in Oceanography

Quantity	Symbol	Units	Comments
Chlorinity	Cl	g kg^{-1}	WG127 is recommending that <i>Chlorinity</i> be defined in terms of a mass fraction as 0.328 523 4 times the ratio of the mass of pure silver required to precipitate all dissolved chloride, bromide and iodide in seawater to the mass of seawater. Hence WG127 recommends that mass fraction units are used for Chlorinity.
Standard Ocean Reference Salinity	S_{SO}	g kg^{-1}	35.165 04 g kg^{-1} being exactly 35 u_{PS} , corresponding to the standard ocean Practical Salinity of 35.
Freezing temperatures	t^f, θ^f, Θ^f	$^{\circ}\text{C}$	<i>In situ</i> , potential and conservative values, each as a function of S_A and p .
Absolute pressure	P	Pa	When absolute pressure is used it should always be in Pa, not in Mpa nor in dbar.
Sea pressure. Sea pressure is the pressure argument to all software in the GSW Toolbox.	p	dbar	Equal to $P - P^0$ and usually expressed in dbar not Pa.

Gauge pressure. Gauge pressure (also called applied pressure) is sometimes reported from ship-born instruments.	p^{gauge}	dbar	Equal to the absolute pressure P minus the local atmospheric pressure at the time of the instrument calibration, and expressed in dbar not Pa. Sea pressure p is preferred over gauge pressure p^{gauge} , as p is the argument to the seawater Gibbs function.
Reference pressure	p_r	dbar	The value of the sea pressure p to which potential temperature and/or potential density are referenced.
One standard atmosphere	P_0	Pa	exactly 101 325 Pa (= 10.1325 dbar)
Isopycnal slope ratio	r	1	$r = \frac{\alpha^\theta(p)/\beta^\theta(p)}{\alpha^\theta(p_r)/\beta^\theta(p_r)}$
Stability ratio	R_ρ	1	$R_\rho = \alpha^\theta \Theta_z / \beta^\theta (S_A)_z \approx \alpha^\theta \theta_z / \beta^\theta (S_A)_z$.
Isopycnal temperature gradient ratio	G^Θ	1	$G^\Theta = r[R_\rho - 1] / [R_\rho - r]$; $\nabla_\sigma \Theta = G^\Theta \nabla_n \Theta$
Practical Salinity	S_p	1	Defined in the range $2 < S_p < 42$ by PSS-78 based on measured conductivity ratios.
Reference Salinity	S_R	g kg^{-1}	Reference-Composition Salinity (or Reference Salinity for short) is the Absolute Salinity of seawater samples that have Reference Composition. At $S_p = 35$, S_R is exactly $u_{\text{PS}} S_p$ while in the range $2 < S_p < 42$ $S_R \approx u_{\text{PS}} S_p$.
Absolute Salinity (This is the salinity argument to all the GSW Toolbox functions.)	$S_A = S_A^{\text{dens}}$	g kg^{-1}	$S_A = S_R + \delta S_A \approx u_{\text{PS}} S_p + \delta S_A$ Absolute Salinity is the sum of S_R on the Millero <i>et al.</i> (2008a) Reference-Salinity Scale and the Absolute Salinity Anomaly. The full symbol for S_A is S_A^{dens} as it is the type of absolute salinity which delivers the best estimate of density when used as the salinity argument of the TEOS-10 Gibbs function. Another name for $S_A = S_A^{\text{dens}}$ is “Density Salinity”.
Absolute Salinity Anomaly	δS_A	g kg^{-1}	$\delta S_A = S_A - S_R$, the difference between Absolute Salinity, $S_A = S_A^{\text{dens}}$, and Reference-Composition Salinity. An algorithm to evaluate δS_A is available (McDougall <i>et al.</i> (2010a)). In terms of the full nomenclature of Pawlowicz <i>et al.</i> (2010), Wright <i>et al.</i> (2010b) and appendix A.4 herein, the Absolute Salinity Anomaly δS_A is δS_R^{dens} .
“Preformed Absolute Salinity”, often shortened to “Preformed Salinity”	S_*	g kg^{-1}	Preformed Absolute Salinity S_* is a salinity variable that is designed to be as conservative as possible, by removing the estimated biogeochemical influences on the seawater composition from other forms of salinity (see Pawlowicz <i>et al.</i> (2010), Wright <i>et al.</i> (2010b) and appendix A.4 herein).
“Solution Absolute Salinity”, often shortened to “Solution Salinity”	S_A^{soln}	g kg^{-1}	The mass fraction of non-H ₂ O constituents in seawater after it has been brought to chemical equilibrium at $t = 25^\circ\text{C}$ and $p = 0$ dbar (see Pawlowicz <i>et al.</i> (2010), Wright <i>et al.</i> (2010b) and appendix A.4 herein).
“Added-Mass Salinity”	S_A^{add}	g kg^{-1}	$S_A^{\text{add}} - S_R$ is the estimated mass fraction of non-H ₂ O constituents needed as ingredients to be added to Standard Seawater which when mixed and brought to chemical equilibrium at $t = 25^\circ\text{C}$ and $p = 0$ dbar results in the observed seawater composition.

Temperature	t	°C	
Absolute Temperature	T	K	$T / \text{K} \equiv T_0 / \text{K} + t / (^\circ\text{C}) = 273.15 + t / (^\circ\text{C})$
temperature derivatives	T	K	When a quantity is differentiated with respect to <i>in situ</i> temperature, the symbol T is used in order to distinguish this variable from time.
Celsius zero point	T_0	K	$T_0 \equiv 273.15 \text{ K}$
Potential temperature	θ	°C	Defined implicitly by Eqn. (3.1.3)
Conservative Temperature	Θ	°C	Defined in Eqn. (3.3.1) as exactly potential enthalpy divided by c_p^0 .
A constant “specific heat”, for use with Conservative Temperature	c_p^0	$\text{J kg}^{-1} \text{K}^{-1}$	$c_p^0 \equiv 3991.867\,957\,119\,63 \text{ J kg}^{-1} \text{K}^{-1}$. This 15-digit number is defined to be the exact value of c_p^0 .
Combined standard uncertainty	u_c	Varies	
Enthalpy	H	J	
Specific enthalpy	h	J kg^{-1}	$h = u + (p + P_0)v$. Here p and P_0 must be in Pa not dbar.
Specific potential enthalpy	h^0	J kg^{-1}	Specific enthalpy referenced to zero sea pressure, $h^0 = h(S_A, \theta[S_A, t, p, p_r = 0], p_r = 0)$
Specific isobaric heat capacity	c_p	$\text{J kg}^{-1} \text{K}^{-1}$	$c_p = \partial h / \partial T _{S_A, p}$
Internal energy	U	J	
Specific internal energy	u	J kg^{-1}	
Specific isochoric heat capacity	c_v	$\text{J kg}^{-1} \text{K}^{-1}$	$c_v = \partial u / \partial T _{S_A, v}$
Gibbs function (Gibbs energy)	G	J	
Specific Gibbs function (Gibbs energy)	g	J kg^{-1}	
Specific Helmholtz Energy	f	J kg^{-1}	
Unit conversion factor for salinities	u_{PS}	g kg^{-1}	$u_{\text{PS}} \equiv (35.16504/35) \text{ g kg}^{-1} \approx 1.004\,715\dots \text{g kg}^{-1}$ The first part of this expression is exact. This conversion factor is an important and invariant constant of the 2008 Reference-Salinity Scale (Millero <i>et al.</i> (2008a)).
Entropy	Σ	J K^{-1}	
Specific entropy	η	$\text{J kg}^{-1} \text{K}^{-1}$	In many other publications the symbol s is used for specific entropy.
Density	ρ	kg m^{-3}	
Density anomaly	σ^t	kg m^{-3}	$\rho(S_A, t, 0) - 1000 \text{ kg m}^{-3}$
Potential density anomaly referenced to a sea pressure of 1000 dbar	σ_1	kg m^{-3}	$\rho(S_A, \theta[S_A, t, p, p_r], p_r) - 1000 \text{ kg m}^{-3}$ where $p_r = 1000 \text{ dbar}$
Potential density anomaly referenced to a sea pressure of 4000 dbar	σ_4	kg m^{-3}	$\rho(S_A, \theta[S_A, t, p, p_r], p_r) - 1000 \text{ kg m}^{-3}$ where $p_r = 4000 \text{ dbar}$
Thermal expansion coefficient with respect to <i>in situ</i> temperature	α^t	K^{-1}	$v^{-1} \partial v / \partial T _{S_A, p} = -\rho^{-1} \partial \rho / \partial T _{S_A, p}$
Thermal expansion coefficient with respect to potential temperature θ	α^θ	K^{-1}	$v^{-1} \partial v / \partial \theta _{S_A, p} = -\rho^{-1} \partial \rho / \partial \theta _{S_A, p}$

Thermal expansion coefficient with respect to Conservative Temperature Θ	α^Θ	K^{-1}	$v^{-1}\partial v / \partial \Theta _{S_A, p} = -\rho^{-1}\partial \rho / \partial \Theta _{S_A, p}$
Saline contraction coefficient at constant <i>in situ</i> temperature	β^t	$kg\ g^{-1}$	$-v^{-1}\partial v / \partial S_A _{T, p} = \rho^{-1}\partial \rho / \partial S_A _{T, p}$ Note that the units for β^t are consistent with S_A being in $g\ kg^{-1}$.
Saline contraction coefficient at constant potential temperature	β^θ	$kg\ g^{-1}$	$-v^{-1}\partial v / \partial S_A _{\theta, p} = \rho^{-1}\partial \rho / \partial S_A _{\theta, p}$ Note that the units for β^θ are consistent with S_A being in $g\ kg^{-1}$.
Saline contraction coefficient at constant Conservative Temperature	β^Θ	$kg\ g^{-1}$	$-v^{-1}\partial v / \partial S_A _{\Theta, p} = +\rho^{-1}\partial \rho / \partial S_A _{\Theta, p}$ Note that the units for β^Θ are consistent with S_A being in $g\ kg^{-1}$.
Isothermal compressibility	κ^t	Pa^{-1}	
Isentropic and isohaline compressibility	κ	Pa^{-1}	
Chemical potential of water in seawater	μ^w	$J\ g^{-1}$	
Chemical potential of sea salt in seawater	μ^s	$J\ g^{-1}$	
Relative chemical potential of (sea salt and water in) seawater	μ	$J\ g^{-1}$	$(\partial g / \partial S_A)_{t, p} = \mu^s - \mu^w$
Dissipation rate of kinetic energy per unit mass	ε	$J\ kg^{-1}\ s^{-1} = m^2\ s^{-3}$	
Adiabatic lapse rate	Γ	$K\ Pa^{-1}$	$\Gamma = \frac{\partial t}{\partial P} _{S_A, \theta} = \frac{\partial t}{\partial P} _{S_A, \Theta} = \frac{\partial t}{\partial P} _{S_A, \eta}$
Sound speed	c	$m\ s^{-1}$	
Specific volume	v	$m^3\ kg^{-1}$	$v = \rho^{-1}$
Specific volume anomaly	δ	$m^3\ kg^{-1}$	
Thermobaric coefficient based on θ	T_b^θ	$K^{-1}Pa^{-1}$	$T_b^\theta = \beta^\theta \partial (\alpha^\theta / \beta^\theta) / \partial P _{S_A, \theta}$
Thermobaric coefficient based on Θ	T_b^Θ	$K^{-1}Pa^{-1}$	$T_b^\Theta = \beta^\Theta \partial (\alpha^\Theta / \beta^\Theta) / \partial P _{S_A, \Theta}$
Cabbeling coefficient based on θ	C_b^θ	K^{-2}	$C_b^\theta = \partial \alpha^\theta / \partial \theta _{S_A, p} + 2 \frac{\alpha^\theta}{\beta^\theta} \partial \alpha^\theta / \partial S_A _{\theta, p} - \left(\frac{\alpha^\theta}{\beta^\theta}\right)^2 \partial \beta^\theta / \partial S_A _{\theta, p}$
Cabbeling coefficient based on Θ	C_b^Θ	K^{-2}	$C_b^\Theta = \partial \alpha^\Theta / \partial \Theta _{S_A, p} + 2 \frac{\alpha^\Theta}{\beta^\Theta} \partial \alpha^\Theta / \partial S_A _{\Theta, p} - \left(\frac{\alpha^\Theta}{\beta^\Theta}\right)^2 \partial \beta^\Theta / \partial S_A _{\Theta, p}$
Buoyancy frequency	N	s^{-1}	$N^2 = g(\alpha^\Theta \Theta_z - \beta^\Theta S_{A_z}) = g(\alpha^\theta \theta_z - \beta^\theta S_{A_z})$
Neutral helicity	H^n	m^{-3}	Defined by Eqns. (3.13.1) and (3.13.2)
Neutral Density	γ^n	$kg\ m^{-3}$	A density variable whose iso-surfaces are designed to be approximately neutral, i. e. $\alpha^\Theta \nabla_\gamma \Theta \approx \beta^\Theta \nabla_\gamma S_A$.
Neutral-Surface-Potential-Vorticity	$NSPV$	s^{-3}	$NSPV = -g\rho^{-1}f\gamma_z^n$ where f is the Coriolis parameter.
Dynamic height anomaly	Φ'	$m^2\ s^{-2}$	$Pa\ m^3\ kg^{-1} = m^2\ s^{-2}$
Montgomery geostrophic streamfunction	π	$m^2\ s^{-2}$	$Pa\ m^3\ kg^{-1} = m^2\ s^{-2}$

PISH (Pressure-Integrated Steric Height)	Ψ'	kg s^{-2}	Streamfunction for f times the depth-integrated relative mass flux, see Eqns. (3.31.1) – (3.31.5).
Coriolis parameter	f	s^{-1}	$1.458\,42 \times 10^{-4} \sin \phi \text{ s}^{-1}$, where ϕ is latitude
Molality	m_{sw}	mol kg^{-1}	$m_{\text{sw}} = \sum_i m_i = \frac{1}{M_S} \frac{S_A}{(1-S_A)}$ where M_S is the mole-weighted average atomic weight of the elements of sea salt, $M_S = 0.031\,403\,821\,8 \dots \text{kg mol}^{-1}$
Ionic strength	I	mol kg^{-1}	$I = \frac{1}{2} m_{\text{sw}} \langle Z^2 \rangle = \frac{1}{2} \sum_i m_i z_i^2$ $= 0.622\,644\,9 m_{\text{sw}}$ $\approx \frac{622.644\,9}{31.403\,821\,8} \text{mol kg}^{-1} \frac{S_A}{(1-S_A)}$
Osmotic coefficient	ϕ	1	$\phi(S_A, T, p) = \frac{g(0, t, p) - \mu^{\text{w}}(S_A, t, p)}{m_{\text{sw}} R (T_0 + t)}$ where the molar gas constant, $R = 8.314\,472 \text{ J mol}^{-1} \text{ K}^{-1}$. See also Eqn. (3.40.9) for an equivalent definition of ϕ .