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. 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 GSW functions are listed on the central two pages of this document. These two pages are also available as a separate double-sided laminated A4 page for ready reference. Printed versions of the present document and of the laminated list of GSW functions are available from the authors. The GSW functions are grouped under several headings of functions with similar characteristics. The first group, called "documentation set" contains tools to assist the user with the GSW Toolbox. By running **gsw_front_page** the user gains access to many of the introductory documents that are found on the TEOS-10 web site, www.TEOS-10.org. Essentially **gsw_front_page** is the front page to the GSW Oceanographic Toolbox, and from this front page much of the TEOS-10 documentation is available (including the present document). 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 GSW 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. **gsw_demo** runs and displays results from several of the GSW functions, so introducing the user to some of the features of the Toolbox.

The second group of functions are the PSS-78 routines for Practical Salinity in terms of either conductivity *C* or conductivity ratio *R*, as well as their inverse functions. The input temperature to these functions is *in situ* temperature (ITS-90), and the inverse algorithms are iterated until the Practical Salinity is equal to the input value to within $2\text{x}10^{-14}$, that is, to machine precision. These functions incorporate a modified form of the extension of Hill *et al*. (1986) to Practical Salinities between zero and 2. The modification ensures that the algorithm is exactly PSS-78 for $S_P \geq 2$ and is continuous at $S_P = 2$. The last function in this group, **gsw_SP_salinometer**, calculates Practical Salinity from the two outputs of a laboratory salinometer, namely R_t and the bath temperature.

The third group delivers the three new oceanographic variables, Absolute Salinity S_A, Preformed Salinity S_*, and Conservative Temperature Θ. The first two functions have Practical Salinity S_P, pressure, longitude and latitude as input variables. Note that virtually all of the functions which follow this third group require Absolute Salinity S_A as an input. Hence it is clear that when analyzing oceanic data, the very first function call must be to **gsw_SA_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 of seawater composition, in which case the remaining GSW functions would be called with Reference Salinity S_R (given by calling **gsw_SR_from_SP**) in place of S_A. The function **gsw_CT_from_t** evaluates Conservative Temperature Θ, as a function of Absolute Salinity S_A, *in situ* temperature t and pressure p.

The fourth group contains just the function **gsw_SA_CT_plot** which plots the TEOS-10 version of the "*T-S*" diagram for a series of vertical profiles. The Conservative Temperature at the freezing point for $p = 0$ dbar, and user-selected potential density contours are also displayed on this $S_A - \Theta$ diagram using the 48-term expression for the density of seawater, **gsw_rho_CT**(SA,CT,p).

The fifth grouping of functions has the heading "other conversions between temperatures, salinities, entropy, pressure and height". Some of these functions are the reverse of those in the previous 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**(SA,t,p,p_ref) which evaluates the potential temperature of the "bottle" (SA,t,p) referenced to the pressure p_ref.

The next four groups of functions are all derived from the computationally-efficient 48-term expression for density, $\hat{\rho}(S_A, \Theta, p)$ of McDougall *et al*. (2011b) (as summarized in appendices A.30 and K of IOC *et al*. (2010)). The first group called "density and enthalpy, based on the 48-term expression for density, $\hat{\rho}(S_A, \Theta, p)$" contains the function **gsw_rho_CT** to evaluate both density and potential density, and **gsw_alpha_CT** to evaluate the relevant thermal expansion coefficient. This 48-term expression for density is essentially as accurate as the full TEOS-10 expression for density, and this 48-term expression has the advantage that its temperature argument is Conservative Temperature. The functions **gsw_enthalpy_CT** and **gsw_enthalpy_diff_CT** are used when evaluating various geostrophic streamfunctions, since under isentropic and isohaline conditions, enthalpy is the pressure integral of specific volume. The functions **gsw_SA_from_rho_CT** and **gsw_CT_from_rho** are essential the inverse functions of the equation of state in that they return the Absolute Salinity (or Conservative Temperature respectively) for given values of density, pressure and either Θ or S_A respectively. Note that all of the functions in this group which end in "_CT" can also be called without the last "_CT" of each function name. For example, the functions **gsw_rho**(SA,CT,p) and **gsw_rho_CT**(SA,CT,p) are identical. Both forms of the function names have been retained so that the functional dependence on Θ rather than on t can be emphasized in this table.

The next group of three functions delivers variables which are defined in terms of the vertical gradients of S_A and Θ on an individual vertical profile, and so are inherently water column properties. These functions deliver the square of the buoyancy frequency (**gsw_Nsquared**), the Turner angle, and the ratio of the vertical gradient of potential density to the vertical gradient of locally-referenced potential density.

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 (**gsw_cabbeling**) and the thermobaric coefficient (**gsw_thermobaric**) which are concerned with how the non-linear nature of the equation of state causes mean diapycnal advection in the ocean, even in the absence of small-scale diapycnal mixing.

The following group is for calculating four different geostrophic streamfunctions. All of these GSW geostrophic streamfunction functions have S_A and Θ as their input salinity and temperature. It is important to realize that a particular geostrophic streamfunction is only accurate when used in the surface for which it is derived. For example, dynamic height anomaly is the geostrophic streamfunction in an isobaric surface while the Montgomery streamfunction 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 streamfunction, while the "isopycnal" geostrophic streamfunction **gsw_geo_strf_isopycnal** of McDougall and Klocker (2010) is the most accurate (see Figures 1, 2 and 3 of McDougall and Klocker (2010)).

The next group contains just the one function, **gsw_geostrophic_velocity**, which calculates the geostrophic velocity in a given surface with respect to the velocity in a reference surface. This function should be called with dynamic height anomaly if the surface in which the geostrophic velocity is required is an isobaric surface. Similarly, **gsw_geostrophic_velocity** should be called with the "isopycnal" geostrophic streamfunction

gsw_geo_strf_isopycnal if the surface in which the geostrophic velocity is evaluated is an approximately neutral surface (such as a Neutral Density surface (Jackett and McDougall (1997)), an ω-surface (Klocker *et al*. (2010)) or a potential density surface).

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

The following group gives the freezing temperatures of seawater (both the Conservative Temperature and the *in situ* temperature at freezing). These freezing temperatures are functions of Absolute Salinity, pressure and the air saturation_fraction (which must be between 0 and 1). The functions **gsw_brineSA_CT** and **gsw_brineSA_t** return the Absolute Salinity at which seawater freezes at given values of Conservative Temperature (or *in situ* temperature, respectively), pressure and saturation_fraction. This group is followed by a group of functions which gives the latent heats of melting and of evaporation.

The next group, "planet Earth properties", delivers straightforward properties of the rotating planet of the solar system on which we presently reside.

The following group, "Absolute Pressure P and sea pressure p" contains two functions for transforming between these two different types of pressure.

The group "TEOS-10 constants" simply returns various constants which are basic to TEOS-10. Note that the constant **gsw_C3515** is not a fundamental constant of either PSS-78 or TEOS-10 but is required to convert a measured conductivity value C into conductivity ratio R (which *is* a fundamental property of PSS-78).

The final two groups contain only functions evaluated using the full TEOS-10 Gibbs function (being the sum of the IAPWS-09 and IAPWS-08 Gibbs functions). The group of GSW functions, headed "density and enthalpy in terms of CT, based on the exact Gibbs function" delivers exactly the same outputs as the corresponding group based on the 48-term expression for density, $\hat{\rho}(S_{\mathrm{A}}, \Theta, p)$, having also the same inputs as those functions. The functions in this group can be used to confirm that the use of the 48-term computationally efficient equation of state does not noticeably degrade any output property.

The final group of GSW functions is headed "basic thermodynamic properties in terms of in-situ t, based on the exact Gibbs function". These functions have *in situ* temperature t as their input temperature variable. All the functions in this group use the full TEOS-10 Gibbs function, namely the sum of the Gibbs functions of IAPWS-09 and IAPWS-08 (rather than the 48-term expression for density). Many of the functions in this group are called by the functions in the previous group.

The GSW Oceanographic Toolbox is designed to be comprehensive and to be installed in its entirety, even though most users may use relatively few of the functions for routine oceanographic analyses. For example, the most basic use of the GSW Oceanographic Toolbox would begin 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 then **gsw_CT_from_t** to convert to a data set of $(S_{\mathrm{A}}, \Theta, p)$. With the data set in this form, water masses may be analyzed accurately on the $S_{\mathrm{A}} - \Theta$ diagram, and *in situ* density and potential density are available by calling the computationally-efficient 48-term expression for density, **gsw_rho**, with the pressure input being the *in situ* sea pressure p, and the reference sea pressure p_ref, respectively. That is, in situ density is evaluated as **gsw_rho**(SA,CT,p) and potential density with respect to the reference pressure p_ref is given by **gsw_rho**(SA,CT,p_ref).

In addition to the functions discussed above and listed on the central two pages of this document, there is an additional group of library functions which are listed below. These 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. The data set gsw_data_v3_0 must not be tampered with.

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

The GSW functions on pages 14 and 15 call the following library functions,

gsw_gibbs	the TEOS-10 Gibbs function and its derivatives
gsw_SAAR	Absolute Salinity Anomaly Ratio (excluding the Baltic Sea)
gsw_Fdelta	ratio of Absolute to Preformed Salinity, minus 1
gsw_delta_SA_ref	Absolute Salinity Anomaly ref. value (excluding the Baltic Sea)
gsw_SA_from_SP_Baltic	Absolute Salinity from SP in the Baltic Sea
gsw_SP_from_SA_Baltic	Practical Salinity from SA in the Baltic Sea
gsw_infunnel	"oceanographic funnel" check for the 48-term density 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_ref_cast	linearly interpolates the reference cast of the isopycnal streamfunction
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_p	specvol_CT(35.16504,0,p)
gsw_enthalpy_SSO_0_p	enthalpy_CT(35.16504,0,p)
gsw_Hill_ratio_at_SP2	Hill ratio at a Practical Salinity of 2

The GSW data set

gsw_data_v3_0 contains

(1) the global data set of Absolute Salinity Anomaly Ratio, R^{δ},

(2) the global data set of Absolute Salinity Anomaly ref., δS_A^{ref},

(3) a reference cast (for the isopycnal streamfunction),

(4) two reference casts that are used by gsw_demo, and

(5) 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.

Licences and 3rd party software

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