1. Preamble

The International Thermodynamic Equation Of Seawater – 2010 (TEOS-10) allows all the thermodynamic properties of pure water, ice, seawater and moist air to be evaluated in a self-consistent manner. For the first time the effects of the variations in seawater composition around the world ocean are accounted for; these spatial variations of seawater composition cause density differences that are equivalent to ten times the precision of our Practical Salinity measurements at sea.

The GSW Oceanographic Toolbox of TEOS-10 is concerned primarily with the properties of pure liquid water and of seawater; the TEOS-10 software for evaluating the properties of ice and of humid air is available in the SIA (Seawater-Ice-Air) software library from the TEOS-10 web site, 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 in this document, and then the use of these variables is discussed, followed by the complete listing and description of the functions available in the GSW toolbox.

Absolute Salinity is the salinity argument of the TEOS-10 algorithms which give the various thermodynamic properties of seawater, and under TEOS-10 Absolute Salinity S_{A} is the salinity variable to be used in scientific publications. Note, however, it is Practical Salinity S_{P} which must be reported to and stored in national databases. The practice of storing one type of salinity in national databases (Practical Salinity), but using a different type of salinity in publications (Absolute Salinity), is exactly analogous to our present practice with temperature; *in situ* temperature is stored in databases (since it is the measured quantity), but the temperature variable that is used in publications is a calculated quantity, being potential temperature to date, and from now, Conservative Temperature.

For the past thirty years, under EOS-80 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 in order to analyze and publish water-mass characteristics on the $S_{\mathrm{P}}-\theta$ diagram. On this $S_{\mathrm{P}}-\theta$ 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}. TEOS-10 also defines a new temperature variable, Conservative Temperature Θ, which takes the place of potential temperature θ. Conservative Temperature Θ has the advantage over θ of more accurately representing the "heat content" of seawater. Under TEOS-10 is not possible to draw isolines of potential density on a $S_{\mathrm{P}}-\theta$ diagram. Rather, because of the spatial variations of seawater composition, a given value of potential density defines an area on the $S_{\mathrm{P}}-\theta$ diagram, not a curved line. Hence for the analysis and publication of ocean data under TEOS-10 we need to change from using the $S_{\mathrm{P}}-\theta$ diagram which was appropriate under EOS-80, to using the $S_{\mathrm{A}}-\Theta$ diagram. It is on this $S_{\mathrm{A}}-\Theta$ diagram that the isolines of potential density can be drawn under TEOS-10.

As a fast-track precursor to the rest of this document, we note that these calculations can be performed using the functions of the GSW Oceanographic Toolbox as follows. The observed variables $\left(S_{\mathrm{P}}, t, p\right)$, together with longitude and latitude, are used to first form Absolute Salinity S_{A} using **gsw_SA_from_SP**, and then Conservative Temperature Θ is calculated using **gsw_CT_from_t**. Oceanographic water masses are then analyzed on the $S_{\mathrm{A}}-\Theta$ diagram (using **gsw_SA_CT_plot**), and potential density contours can be drawn on this $S_{\mathrm{A}}-\Theta$ diagram using **gsw_rho**(SA,CT,p_ref).

The more prominent advantages of TEOS-10 compared with EOS-80 are

- For the first time the influence of the spatially varying composition of seawater is systematically taken into account through the use of Absolute Salinity S_{A}. In the open ocean, this has a non-trivial effect on the horizontal density gradient, and thereby on ocean velocities and "heat" transports calculated via the "thermal wind" relation.
- The new salinity variable, Absolute Salinity S_{A}, is measured in SI units (e.g. $\mathrm{g\ kg^{-1}}$).
- The Gibbs function approach of TEOS-10 allows the calculation of internal energy, entropy, enthalpy, potential enthalpy and the chemical potentials of seawater as well as the freezing temperature, and the latent heats of melting and of evaporation. These quantities were not available from EOS-80 but are essential for the accurate accounting of "heat" in the ocean and for the consistent and accurate treatment of air-sea and ice-sea heat fluxes in coupled climate models.
- In particular, Conservative Temperature Θ accurately represents the "heat content" per unit mass of seawater, and is to be used in place of potential temperature θ in oceanography.
- The thermodynamic quantities available from TEOS-10 are totally consistent with each other, while this was not the case with EOS-80.
- A single algorithm for seawater density (the 48-term computationally-efficient expression $\hat{\rho}\left(S_{\mathrm{A}},\Theta,p\right)$) can now be used for ocean modelling, for observational oceanography, and for theoretical studies. By contrast, for the past 30 years we have used different algorithms for density in ocean modelling and in observational oceanography and inverse modelling.

The present document (McDougall and Barker, 2011) provides a short description of the three new oceanographic variables S_{A}, S_* and Θ, leading into a discussion of the changes to observational oceanography and ocean modelling under TEOS-10 (compared with EOS-80), and then we list and describe the functions in the GSW Oceanographic Toolbox. The present document ends 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). Another document "What every oceanographer needs to know about TEOS-10 (The TEOS-10 Primer)" (Pawlowicz, 2010) provides a succinct introduction to the thermodynamic theory underlying TEOS-10 and is available from www.TEOS-10.org.

Note that when referring to the use of TEOS-10, it is the TEOS-10 Manual which should be referenced as IOC *et al.* (2010) [IOC, SCOR and IAPSO, 2010: *The international thermodynamic equation of seawater – 2010: Calculation and use of thermodynamic properties*. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English), 196 pp.].