

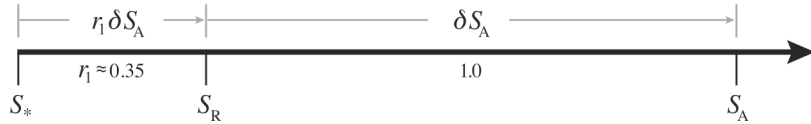
## 4. Preformed Salinity $S_*$

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 interpolates the global Absolute Salinity Anomaly Ratio ( $R^\delta$ ) data set using the internal GSW library function **gsw\_SAAR** to the (p,long,lat) location. **gsw\_Sstar\_from\_SP** then uses this interpolated value of  $R^\delta$  to calculate Preformed Salinity  $S_*$  according to (see Eqn. (A.5.11) of appendix A.5 of the TEOS-10 Manual, IOC *et al.* (2010))

$$S_* = \frac{35.165\,04\,\text{g kg}^{-1}}{35} S_p (1 - r_1 R^\delta), \quad \text{Non-Baltic} \quad (3)$$

where  $r_1$  is taken to be the constant 0.35 based on the work of Pawlowicz *et al.* (2011). Note that  $(35.165\,04\,\text{g kg}^{-1}/35) S_p$  is Reference Salinity  $S_R$  which is the best estimate of Absolute Salinity for a Standard Seawater sample. The figure below (from Figure A.4.1 of the TEOS-10 Manual, IOC *et al.*, 2010) illustrates the relationships between Preformed Salinity  $S_*$ , Reference Salinity  $S_R$  and Absolute Salinity  $S_A$ .



**Figure A.4.1.** Number line of salinity, illustrating the differences between Preformed Salinity  $S_*$ , Reference Salinity  $S_R$ , and Absolute Salinity  $S_A$  for seawater whose composition differs from that of Standard Seawater.

Equation (3) is the value of Preformed Salinity  $S_*$  returned by **gsw\_Sstar\_from\_SP** unless the function detects that the location is in the Baltic Sea (where incidentally the internal GSW library function **gsw\_SAAR** returns a value of  $R^\delta$  of zero). In the Baltic Sea the deviations of Absolute Salinity from Reference Salinity are not 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 Absolute Salinity  $S_A$ . Hence, if the observation is from the Baltic Sea, Preformed Salinity  $S_*$  is calculated using the relation  $S_A - S_R = 0.087\,\text{g kg}^{-1} \times (1 - S_p/35)$  (from Eqn. (A.5.6) of IOC *et al.* (2010), following Feistel *et al.* (2010)), so that

$$S_* = S_A = \frac{(35.165\,04 - 0.087)\,\text{g kg}^{-1}}{35} S_p + 0.087\,\text{g kg}^{-1}. \quad \text{Baltic Sea} \quad (4)$$

In summary, the **gsw\_Sstar\_from\_SP** function returns either Eqn. (3) or Eqn. (4) depending on whether the longitude and latitude of the sample put the observation outside or inside the Baltic Sea. Since Practical Salinity should always be positive but there are sometimes be a few negative values from a CTD, any negative input values of  $S_p$  to this function **gsw\_Sstar\_from\_SP** are set to zero.

If the latitude and longitude are such as to place the observation well away from the ocean, a flag ‘in\_ocean’ is set to zero as a warning, otherwise it is 1. This flag is only set when the observation is well and truly on dry land; often the warning flag is not set until one is several hundred kilometers inland from the coast. When the function detects that the observation is not from the ocean,  $R^\delta$  is set equal to zero and **gsw\_Sstar\_from\_SP** returns  $S_* = S_R = (35.165\,04\text{ g kg}^{-1}/35) S_P$  in accordance with Eqn. (3).

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  $0.036\text{ g kg}^{-1}$ , equivalent 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.

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.