Notes on the function,
gsw_latentheat_evap_CT(SA,CT)

This function, **gsw_latentheat_evap_CT**, finds the "latent heat of evaporation", which is also called the "isobaric evaporation enthalpy", evaluated at the sea surface at $p = 0$ dbar . The output of this function is in units of $J\ kg^{-1}$ while the input variables are Absolute Salinity S_A ($g\ kg^{-1}$) and Conservative Temperature (ITS-90 °C).

The latent heat of evaporation of water from the ocean surface (i. e. at $p = 0$ dbar), L_p^{SA}, is given in terms of the specific enthalpy of moist air, h^{AV}, and the specific enthalpy of seawater, h, by Eqn. (3.39.7) of the TEOS-10 Manual (IOC *et al.* (2010)), repeated here,

$$L_p^{SA}\left(A, S_A, t, p\right) = h^{AV} - A\left.\frac{\partial h^{AV}}{\partial A}\right|_{T,p} - h + S_A\left.\frac{\partial h}{\partial S_A}\right|_{T,p}, \qquad (3.39.7)$$

where S_A is the Absolute Salinity of the seawater from which the water is evaporating (see equation (6.28) of Feistel *et al.* (2010)), and for the purposes of the present function, only $p = 0$ dbar is considered. Also, for the purposes of the present function, **gsw_latentheat_evap_CT**, the air-fraction A is taken to be the value given by equilibrium between humid air and seawater. The present function **gsw_latentheat_evap_CT** is a polynomial fit to data obtained from the SIA (Seawater-Ice-Air) code of TEOS-10. This **gsw_latentheat_evap_CT** function is applicable up to an Absolute Salinity of $42\,g\ kg^{-1}$ and up to a Conservative Temperature of 40 °C , and it fits the SIA values of L_p^{SA} to better than $\pm 1\ J\ kg^{-1}$.

References

Feistel, R., D. G. Wright, H.-J. Kretzschmar, E. Hagen, S. Herrmann and R. Span, 2010: Thermodynamic properties of sea air. *Ocean Science,* **6**, 91–141. http://www.ocean-sci.net/6/91/2010/os-6-91-2010.pdf

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. Available from http://www.TEOS-10.org

Here follows section 3.39 of the TEOS-10 Manual (IOC *et al.* (2010)).

3.39 Latent heat of evaporation

The evaporation process of pure liquid water in contact with pure water vapour can be conducted by supplying heat at constant t and P. The heat required per mass evaporated from the liquid is the latent heat, or enthalpy, of evaporation, L_p^{VW}. It is found as the difference between the specific enthalpy of water vapour, h^{V}, and the specific enthalpy of liquid water, h^{W} :

$$L_p^{\text{VW}}(t) = h^{\text{V}}\left(t, P^{\text{vap}}\right) - h^{\text{W}}\left(t, P^{\text{vap}}\right). \tag{3.39.1}$$

Here, $P^{\text{vap}}(t)$ is the vapour pressure of water at the temperature t (section 3.37). The enthalpies h^{V} and h^{W} are available from IAPWS-95. At the triple point of water, the TEOS-10 evaporation enthalpy is $L_p^{\text{VW}}(0.01°\text{C}) = 2\,500\,915\,\text{J kg}^{-1}$.

In the case of seawater in contact with air, the vapour resulting from the evaporation will add to the gas phase, thus increasing the mole fraction of vapour, while the liquid water loss will increase the brine salinity, and cause a change to the seawater enthalpy. Consequently, the enthalpy related to this phase transition will depend on the particular conditions under which the evaporation process occurs.

Here, we define the latent heat of evaporation as the enthalpy increase per infinitesimal mass of evaporated water of a composite system consisting of seawater and humid air, when the temperature is increased at constant pressure and at constant total masses of water, salt and dry air, in excess of the enthalpy increase needed to warm up the seawater and humid air phases individually (Feistel *et al.* (2010a)). Mass conservation during this thermodynamic process is essential to ensure the independence of the latent heat formula from the unknown absolute enthalpies of air, salt and water that otherwise would accompany any mass exchange.

The enthalpy of sea air, h^{SA}, is additive with respect to its constituents, seawater, h, with the mass fraction w^{SW}, and humid air, h^{AV}, with the gas fraction $\left(1 - w^{\text{SW}}\right)$:

$$h^{\text{SA}} = \left(1 - w^{\text{SW}}\right)h^{\text{AV}}(A, t, p) + w^{\text{SW}}h(S_{\text{A}}, t, p). \tag{3.39.2}$$

Upon warming, the mass of water transferred from the liquid to the gas phase by evaporation reduces the seawater mass fraction w^{SW}, increases the brine salinity S_{A} and increases the humidity, with a corresponding decrease in the dry-air fraction A of the gas phase. The related temperature derivative of Eqn. (3.39.2) is

$$\begin{aligned}
\left.\frac{\partial h^{\text{SA}}}{\partial T}\right|_p &= \left(1 - w^{\text{SW}}\right)\left.\frac{\partial h^{\text{AV}}}{\partial T}\right|_{A,p} + \left(1 - w^{\text{SW}}\right)\left.\frac{\partial h^{\text{AV}}}{\partial A}\right|_{T,p}\left.\frac{\partial A}{\partial T}\right|_p \\
&+ w^{\text{SW}}\left.\frac{\partial h}{\partial T}\right|_{S_{\text{A}},p} + w^{\text{SW}}\left.\frac{\partial h}{\partial S_{\text{A}}}\right|_{T,p}\left.\frac{\partial S_{\text{A}}}{\partial T}\right|_p + \left(h - h^{\text{AV}}\right)\left.\frac{\partial w^{\text{SW}}}{\partial T}\right|_p.
\end{aligned} \tag{3.39.3}$$

The isobaric evaporation rate $\left. -\partial w^{\text{SW}} / \partial T\right|_p$ is related to the air-fraction change by the conservation of the dry air, $\left(1 - w^{\text{SW}}\right)A = \text{const}$, in the form

$$\left.\frac{\partial A}{\partial T}\right|_p = \frac{A}{1 - w^{\text{SW}}}\left.\frac{\partial w^{\text{SW}}}{\partial T}\right|_p, \tag{3.39.4}$$

and to the change of salinity by the conservation of the salt, $w^{\text{SW}}S_{\text{A}} = \text{const}$, in the form

$$\left.\frac{\partial S_{\text{A}}}{\partial T}\right|_p = -\frac{S_{\text{A}}}{w^{\text{SW}}}\left.\frac{\partial w^{\text{SW}}}{\partial T}\right|_p. \tag{3.39.5}$$

Using these relations, Eqn. (3.39.3) takes the simplified form

$$\left.\frac{\partial h^{\text{SA}}}{\partial T}\right|_p = \left(1 - w^{\text{SW}}\right)c_p^{\text{AV}} + w^{\text{SW}}c_p - L_p^{\text{SA}}\left.\frac{\partial w^{\text{SW}}}{\partial T}\right|_p. \tag{3.39.6}$$

The coefficient in front of the evaporation rate,

$$L_p^{SA}\left(A, S_A, t, p\right) = h^{AV} - A\frac{\partial h^{AV}}{\partial A}\bigg|_{T,p} - h + S_A\frac{\partial h}{\partial S_A}\bigg|_{T,p}, \qquad (3.39.7)$$

provides the desired expression for isobaric evaporation enthalpy, namely the difference between the partial specific enthalpies of vapour in humid air (the first two terms) and of water in seawater (the last two terms). In the ideal-gas approximations for air and for vapour, the partial specific enthalpy of vapour in humid air, $h^{AV} - Ah_A^{AV}$, equals the specific enthalpy of vapour, $h^V(t)$, as a function of only the temperature, independent of the pressure and of the presence of air (Feistel *et al.* (2010a)). As is physically required for any measurable thermodynamic quantity, the arbitrary absolute enthalpies of water, salt and air cancel in the formula (3.39.7), provided that the reference state conditions for both the seawater and the humid-air formulation are chosen consistently (Feistel *et al.* (2008a), (2010a)). The latent heat of evaporation depends only weakly on salinity and on air fraction, and is an almost linear function of the temperature and of the pressure.

Selected representative values for the air fraction at condensation, A^{cond}, and the latent heat of evaporation, L_p^{SA}, are given in Table 3.39.1.

Table 3.39.1: Selected values for the equilibrium air fraction, A^{cond}, computed from Eqn. (3.37.6), and the latent heat of evaporation, L_p^{SA}, computed from Eqn. (3.39.7), for different sea-surface conditions. Note that the TEOS-10 formulation for humid-air is valid up to 5 MPa, i.e., almost 500 dbar sea pressure.

Condition	S_A g kg^{-1}	t °C	p dbar	A^{cond} %	L_p^{SA} J kg^{-1}
Pure water	0	0	0	99.622 31	2 499 032
Brackish water	10	0	0	99.624 27	2 499 009
Standard ocean	35.165 04	0	0	99.629 31	2 498 510
Tropical ocean	35.165 04	25	0	98.059 33	2 438 971
High pressure	35.165 04	0	400	99.989 43	2 443 759

In the derivation of Eqn. (3.39.7), the value of A is indirectly assumed to be computed from the equilibrium condition (3.37.6) between humid air and seawater, $A = A^{cond}$. At this humidity the air is still sub-saturated, $A^{cond} > A^{sat}$, but its vapour starts condensing at the sea surface. The values of A^{cond} and A^{sat} coincide only below the freezing point of seawater, or at vanishing salinity, see also the following section 3.40.

The evaporation rate, $-\partial w^{SW}/\partial T\big|_p$, can be computed from Eqn. (3.37.6), the equilibrium condition between humid air and seawater, at changing temperature and constant pressure (Feistel *et al.* (2010a)). In contrast, the derivation of L_p^{SA} using Eqns. (3.39.2) - (3.39.7) is a mere consideration of mass and enthalpy balances; no equilibrium condition is actually involved. Hence, it is physically evident that Eqn. (3.39.7) can also be applied to situations in which A takes any given value different from A^{cond}, that is, it can be applied regardless of whether or not the humid air is actually at equilibrium with the sea surface.