2024 IAPWS Gibbs Award Lecture: Thermodynamics of Water in the "Steam Engine" Climate

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Climate is changing: the world is getting warmer. Of the mean solar energy flux of 240 W m^{-2}, a fraction of 0.5 W m^{-2} remains permanently stored: in the ocean, 89 % of that, 6 % on land, 4 % melt the ice cover, and only 1 % of it heats up the atmosphere; just this bit is publicly recognised from weather forecasts. Climate models estimate the air-sea heat flux with an uncertainty larger than 5 W m^{-2} and tend to underestimate the observed ocean warming. To lay a reliable physical basis for improved prognoses, IAPWS with its Subcommittee on Seawater in cooperation with the SCOR/IAPSO Working Group 127 had developed the new international standard TEOS-10, the Thermodynamic Equation of Seawater – 2010. It provides highly accurate and mutually consistent thermodynamic potentials of seawater, ice and humid air, including enthalpies, entropies and chemical potentials that were previously unavailable in standard formulations. The main export process of heat from the ocean into the atmosphere is evaporation, and this water vapour is the key energy source driving atmospheric dynamics. The chemical potentials of TEOS-10 permit a replacement of historical Dalton equations, still in use for evaporation in climate models, by expressions in terms of the relative fugacity of humid air, eliminating this way a spurious numerical intensification of the hydrological cycle. Relative fugacity may also serve to harmonise the various, mutually inconsistent definitions of relative humidity, such as those used in metrology and climatology. Enthalpies and entropies of TEOS-10 permit potential enthalpy being used as a heat variable rather than historical potential temperature which is not sufficiently well conserved upon mixing. IAPWS activities contribute fundamentally to a better understanding of the warming climate.

References:

1. IAPWS AN6-16 (2016): Advisory Note No. 6: Relationship between Various IAPWS Documents and the International Thermodynamic Equation of Seawater – 2010 (TEOS-10). Dresden, Germany, www.iapws.org
2. Feistel, R. (2018): Thermodynamic properties of seawater, ice and humid air: TEOS-10, before and beyond. Ocean Sci. 14, 471–502, https://doi.org/10.5194/os-14-471-2018
3. Feistel, R. (2008): A Gibbs function for seawater thermodynamics for –6 to 80 °C and salinity up to 120 g kg^{-1}, Deep-Sea Res. Pt. I 55,1639–1671, https://doi.org/10.1016/j.dsr.2008.07.004
4. Feistel, R., Wagner, W. (2006): A new equation of state for H_2O ice I_h. J. Phys. Chem. Ref. Data 35, 1021–1047, https://doi.org/10.1063/1.2183324
5. Feistel, R., Wright, D.G., Kretzschmar, H.-J., Hagen, E., Herrmann, S., Span, R. (2010): Thermodynamic properties of sea air. Ocean Sci. 6, 91–141, https://doi.org/10.5194/os-6-91-2010
6. Feistel, R., Lovell-Smith, J.W. (2017): Defining relative humidity in terms of water activity. Part 1: Definition. Metrologia 54, 566–576, https://doi.org/10.1088/1681-7575/aa7083
7. Feistel, R., Wielgosz, R., Bell, S. A., Camões, M. F., Cooper, J. R., Dexter, P., Dickson, A. G., Fisicaro, P., Harvey, A. H., Heinonen, M., Hellmuth, O., Kretzschmar, H.-J., Lovell-Smith, J. W., McDougall, T. J., Pawlowicz, R., Ridout, R., Seitz, S., Spitzer, P., Stoica, D., Wolf, H. (2016): Metrological challenges for measurements of key climatological observables: Oceanic salinity and pH, and atmospheric humidity. Part 1: overview, Metrologia 53, R1–R11, https://doi.org/10.1088/0026-1394/53/1/R1
8. Feistel, R., Hellmuth, O. (2021): Relative Humidity: A Control Valve of the Steam Engine Climate. J. Hum. Earth Future 2, 140–182, https://doi.org/10. 28991/HEF-2021-02-02-06
9. Feistel, R., Hellmuth, O. (2023): Thermodynamics of Evaporation from the Ocean Surface. Atmosphere 14, 560, https://doi.org/10.3390/atmos14030560