Accurate Measurements of Seawater Density Up to Pressure of 110 MPa Including the Metastable Supercooled Liquid Region

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We present accurate (expanded uncertainty 50-100 ppm) measurements of the density of IAPSO Standard Seawater (batch P161, certified practical salinity 34.995) in temperature range from 298.15 K down to 253.15 K from atmospheric pressure to 60 MPa, and down to 253.15 K at pressures 70 MPa to 110 MPa, thus covering the full pressure range of natural seawater. The experiments extended into the metastable supercooled liquid region. Natural occurrence of supercooled seawater is limited to mild supercooling during freezing and possibly high supercooling for seaspray. However, density measurements beyond the melting line enable to properly determine derivative properties close to the melting line and examine validity of mixture models. The experiments were performed with a newly developed dual capillary dilatometer (DCD, A. Blahut et al., J. Chem. Phys. 151, 034505 (2019)). This device enables accurate measurements of aqueous densities including supercooled states up to pressure of 200 MPa. In addition, measurements with a vibrating tube densimeter (VTD, Anton Paar DMA^{TM} 5000 M) were performed at atmospheric pressure between 275.15 K and 343.15 K. We also employ thermodynamic integration to obtain densities and thermodynamic properties based on our expansivities and literature data for speed of sound.

In the stable liquid region difference between DCD densities and those calculated from TEOS-10 formulation (R. Feistel, Deep Sea Research Part I: Oceanographic Research Papers 55, 1639–1671 (2008); IAPWS R13-08, 2008. Release on the IAPWS Formulation 2008 for the Thermodynamic Properties of Seawater) is mostly lower than 50 ppm, however in the supercooled region the deviations increase more rapidly with decreasing temperature and are larger than 200 ppm below 253 K. The deviations are even clearer for isobaric expansivities. Experimental expansivities are significantly higher (less negative) in the supercooled liquid region than computed from TEOS-10, and the experimental line of maximum density is lower than computed. Also our VTD measurements show a good agreement with TEOS-10 within its range of validity, but deviate strongly at higher temperatures; they are, however, in a fine agreement with equation by Millero and Huang (Ocean Sci. 5, 91–100 (2009)).