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The impact of shallow stratification on air-sea CO_2 flux in the summer Arctic Ocean

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Air-sea carbon dioxide (CO_2) flux is often indirectly estimated by the bulk method using the i*n-situ* air-sea difference in CO_2 fugacity and a wind speed dependent parameterisation of the gas transfer velocity (K). In the summer, sea-ice melt in the Arctic Ocean generates strong shallow stratification with significant gradients in temperature, salinity, dissolved inorganic carbon (DIC) and alkalinity (TA), and thus a near-surface CO_2 fugacity (fCO_{2w}) gradient. This gradient can cause an error in bulk air-sea CO_2 flux estimates when the fCO_{2w} is measured by the ship's underway system at ~5 m depth. Direct air-sea CO_2 flux measurement by eddy covariance (EC) is free from the impact of shallow stratification because the EC CO_2 flux does not rely on a fCO_{2w} measurement. In this study, we use summertime EC flux measurements from the Arctic Ocean to back-calculate the sea surface fCO_{2w} and temperature and compare them with the underway measurements. We show that the EC air-sea CO_2 flux agrees well with the bulk flux in areas less likely to be influenced by ice melt (salinity > 32). However, in regions with salinity less than 32, the underway fCO_{2w} is higher than the EC estimate of surface fCO_{2w} and thus the bulk estimate of ocean CO_2 uptake is underestimated. The fCO_{2w} difference can be partly explained by the surface to sub-surface temperature difference. The EC estimate of surface temperature is lower than the sub-surface water temperature and this difference is wind speed-dependent. Upper-ocean salinity gradients from CTD profiles suggest likely difference in DIC and TA concentrations between the surface and sub-surface water. These DIC and TA gradients likely explain much of the near-surface fCO_{2w} gradient. Accelerating summertime loss of sea ice results in additional meltwater, which enhances near-surface stratification and increases the uncertainty of bulk air-sea CO_2 flux estimates in polar regions.