What triple isotopes of dissolved O_2 tell us about deep water formation in the Arctic Ocean

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The ^{17}O excess of dissolved O_2 ($^{17}\Delta$) in the ocean is a unique property which is useful for telling apart O_2 produced by marine photosynthesis (bio-O_2) from atmospheric O_2. Unlike O_2 concentration, $^{17}\Delta$ is not affected by respiration and thus behaves conservatively in the deep ocean and can be applied for tracing conditions of water mass formation. It is well established that deep water in the Arctic Ocean forms in in winter in the Barents and Kara Seas region by densification due to seawater freezing and associated brine rejection. For the most part, sea-ice formation takes place in latent-heat polynyas where high winds over shallow shelves cause effective gas exchange and $^{17}\Delta$ is expected to be close to zero and near air-sea isotopic equilibrium. Indeed, with an exception of a station off Barents Sea, for the depth range between the Atlantic layer (AW) and about 1500-2000m, $^{17}\Delta$ values are near equilibrium. In contrast, below about 2000m $^{17}\Delta$ values indicate presence of bio-O_2 in all major basins. We suggest that bio-O_2 in arctic deep and bottom waters originates from densification of high-$^{17}\Delta$ seawater produced in summers in the photic zone of the arctic halocline, where stratification effectively slows down air-sea gas exchange. For most of the Arctic Ocean, the density of high-$^{17}\Delta$ seawater is too low such that densification in winter by sea-ice formation and brine rejection cannot cause its sinking to great depth. An exception is in the vicinity of Fram Strait and Barents Sea, where we observed high $^{17}\Delta$ in high salinity water of Atlantic origin. Sufficient densification of this water is possible in winter by cooling and brine addition but at slow gas exchange due to seasonal sea-ice cover. Our new results suggest that the majority of waters below AW and above 1500-2000m originate from latent heat polynyas. In contrast, most 2000m to bottom waters of the Arctic Ocean originate from densification of weak pycnocline waters in the region of Kara and Barents Seas away from the coasts.