# The upper ocean nitrogen cycle in the Atlantic Southern Ocean

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The balance between summertime nitrate ($NO_3^-$) consumption and wintertime $NO_3^-$ recharge is central to the role of the Southern Ocean in setting atmospheric $CO_2$. It is also the most obvious seasonal signal in the concentration and isotopic composition ($\delta^{15}N$ and $\delta^{18}O$) of $NO_3^-$ in Antarctic surface waters. In addition, there may be active cycling of nitrogen (N) within the seasonally varying mixed layer, which remains poorly understood. Measurements of the dual isotopes of $NO_3^-$ show that while $NO_3^-$ assimilation by phytoplankton is the dominant signal in the upper water column of the Antarctic, even in midwinter, nitrification (the oxidation of ammonium ($NH_4^+$) to nitrite ($NO_2^-$) and then $NO_3^-$) is active in the surface mixed layer in winter but not in summer. This is supported by tracer experiments that reveal high rates of $NH_4^+$ and $NO_2^-$ oxidation throughout the Antarctic winter mixed layer, while $NO_3^-$ assimilation is low to undetectable. By contrast, summertime $NO_3^-$ assimilation rates are high and nitrification accounts for <6% of algal $NO_3^-$ consumption. Surprisingly, $NH_4^+$ uptake is extremely high in winter, which, given the low rates of primary production, we attribute to heterotrophic bacteria. Competition for $NH_4^+$ between hetetrophic bacteria and $NH_4^+$ oxidizers may help to explain the anomalously low $\delta^{15}N$ of $NO_3^-$ in the Antarctic winter mixed layer: isotopic fractionation during concurrent assimilation and oxidation of $NH_4^+$, which occur at equivalent rates, would preferentially transfer $^{14}N$ to the newly nitrified $NO_3^-$ pool, lowering its $\delta^{15}N$ beyond that of the particulate organic matter (PON) and $NH_4^+$ available for nitrification at the end of summer. This, coupled with the observation that PON-$\delta^{15}N$ declines in the late summer, likely due to enhanced $NH_4^+$ assimilation by iron-limited phytoplankton, confirms that Antarctic surface waters are characterised by an intense internal N cycle that may partly control the strength of $NO_3^-$ drawdown in summer. Finally, contrary to previous studies, we observe no relationship between mixed layer depth and the degree of isotopic fractionation during $NO_3^-$ assimilation, which has significant implications for reconstructions of past nutrient consumption in Antarctic surface waters.