A Seasonal Model of Nitrogen Isotopes in the Ice Age Antarctic Zone: Support for Weakening of the Southern Ocean Upper Overturning Cell

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In the Antarctic Zone of the Southern Ocean, the coupled observations of elevated diatombound 15N/14N (δ15Ndb) and reduced export production during the ice ages indicates more complete nitrate (NO_3^-) consumption. This evidence points to an ice age decline in gross NO_3^- supply from the deep ocean to the surface windmixed layer, which may help to explain the reduced CO2 levels of the ice age atmosphere. We use a seasonally resolved, twolayer model of the N isotopes in the Antarctic Zone upper ocean to quantify the ice age decline in gross NO_3^- supply implied by the data. When model parameters are varied to reflect reduced gross NO_3^- supply, the concentration of wintertime upper ocean NO_3^- is lowered, but with a much weaker increase in NO_3^- δ15N than predicted by analytical models such as the Rayleigh and steady state models. Physical mixing is the dominant cause, with a modest contribution from foodweb dynamics. As a result, the observed δ15Ndb rise of 3%■–4%■must be explained mostly by a greater summertime increase in NO_3^- δ15N during the ice ages. The high degree of NO_3^- consumption required to generate this summertime δ15N rise indicates a >80% reduction in gross NO_3^- supply. Half or more of the modern gross NO_3^- supply is from windforced Antarctic upwelling that drives the upper cell of Southern Ocean overturning. Thus, the decrease in NO_3^- supply cannot be achieved solely by a decline in vertical mixing or wintertime convection; rather, it requires an ice age weakening of the upper cell.
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