Supporting Information for

Glacial Southern Ocean expansion recorded in foraminifera-bound nitrogen isotopes from the Agulhas Plateau during the Mid-Pleistocene Transition

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Introduction

Here we include the supplemental figures referenced in the above manuscript. Images include complimentary data, subset records, and Rayleigh curve estimates for nutrient consumption.
Figure S1. a. Modern sea surface δ15N\textsubscript{NO3} profile measurements, colored by latitude, showing isotopic enrichment with progressive consumption of the nutrient pool as waters are advected northward (open symbol, solid lines). Red line with closed triangles indicates integrated product +3.1 ‰, species specific elevation for *G. bulloides* over bulk PON at 41°S (Smart et al., 2020; Sigman et al., 1999). Closed shapes with black outlines indicate expected δ15N\textsubscript{FB} (integrated product + 3.1‰) of *G. bulloides* growing in the surface mixed layer at each latitude. Profile data are from Smart et al. (2020).

b. Estimation for nitrate consumption at 41°S. Average δ15N\textsubscript{FB} *G. bulloides* measurements for Holocene (long dash short dash line), average MPT interglacial (dot dash line) are indicated by horizontal lines, corresponding nitrate concentrations are indicated by vertical lines. Red line with closed triangles indicates integrated product +3.1 ‰, species specific δ15N elevation for *G. bulloides* over bulk PON at 41°S (Smart et al., 2020; Sigman et al., 1999). Red dashed line with open triangles shows instantaneous product +3.1 ‰, species specific elevation for *G. bulloides* over bulk PON, at 41°S (Smart et al., 2020).
Figure S2. a. $^{137}\text{U}^{\text{K}}$ derived sea surface temperatures from Sites U1475 (Cartagena-Sierra et al., 2021) and 1090 (Martínez-García et al., 2009) (°C); b. Ice rafted debris mass accumulation rate at Site U1475 (grains/cm$^2$/kyr) (Starr et al., 2021); c. Oxygen isotopes from benthic foraminifera *Cibicidoides wuellerstorfi* at Site U1475 (Starr et al., 2021) (‰); d. Insolation at 80°S (W/m$^2$) (Laskar et al., 2004).
Figure S3. $\delta^{15}$N$_{FB}$ values of *G. bulloides* in glacial periods after 900 ka. Marine isotope stages are numbered on the top axis and blue shading indicates glacial intervals.

Figure S4. Nitrogen content per milligram foraminifera cleaned in each sample (nmol N/mg).
Equation S1. Blank-corrected sample $\delta^{15}$N values are calculated using the equation:

$$
\delta s = \frac{\delta t - \delta b}{n s}
$$

where $\delta s$ is the $\delta^{15}$N value of foram-bound N (as NO$_3^-$), $n_s$ is the concentration of sample NO$_3^-$, $\delta t$ is the measured $\delta^{15}$NNO$_3^-$, $n_t$ is the measured [NO$_3^-$], $\delta b$ is the $\delta^{15}$N value of total N blank, and $n_b$ is the concentration of blank-derived [NO$_3^-$]. We estimated the $\delta^{15}$N value of the persulfate blank using a dilution series (5, 7.5, 10, and 20 μM) of the USGS65 glycine standard and the fraction of the blank in standards. Each batch of samples had a distinct blank value, with a mean value of 5 ± 10‰. We applied the mean blank $\delta^{15}$N value for each sample in the dataset, assuming an error of ±10‰.

Equation S2. The uncertainty of the $\delta^{15}$N value of the blank is propagated to calculate the uncertainty in the oxidized sample $\delta^{15}$N value using the equation:

$$
\sigma^2(\delta s) = (nb \cdot \frac{\delta b - \delta t}{n_t - n_b})^2 \cdot \sigma^2(n_t) + \left(\frac{n_t}{n_t - n_b}\right)^2 \cdot \sigma^2(\delta t) + \left(\frac{n_t \cdot \delta t - \delta b}{n_t - n_b}\right)^2 \cdot \sigma^2(n_b) + \left(\frac{n_b}{n_t - n_b}\right)^2 \cdot \sigma^2(\delta b)
$$