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Isotopic constraints on the marine nitrogen budget in the modern and glacial ocean

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The well-documented relationship between the marine nitrogen cycle and the physical ocean environment in marine sediments suggests that anthropogenic climate change will impact the marine ecosystem. However, the strength and nature of this coupling are poorly quantified. Here, we investigate how natural climate changes affected the marine nitrogen cycle from the last glacial maximum ($\sim$20 ka) to present, by comparing a new global database of sedimentary nitrogen isotope (δ^{15}N) measurements with experiments from a coupled ocean-biogeochemistry-isotope model. These δ^{15}N patterns can be explained by the interplay between N2 fixation (the main source of oceanic nitrogen provided by specialized phytoplankton), N-loss processes occurring in suboxic zones ($O_2 < 10\ \mu$M), and the utilization of surface nitrate by phytoplankton, as confirmed by good agreement with the results of a coupled model integrated under pre-industrial forcing. The model experiment that best reproduces seafloor δ^{15}N observations estimates rates of N_2 fixation, water column N-loss, and benthic N-loss were approximately 350, 80, and 270 Tg N yr^{-1}. This model result suggests that the residence time for the marine nitrogen inventory is $<$ 1,000 years in the pre-industrial ocean, which would make it susceptible to major fluctuations on multi-centennial to millennial timescale climate change. A compilation of 78 sediment cores reveals that the climate changes of the last ice age and deglaciation wrought global-scale changes in nitrogen cycling. In the modern ocean, high-latitude nitrate utilization by phytoplankton was reduced, while both N-loss processes and N2 fixation operated at higher rates. The coupled model predicts N_2 fixation and N-loss rates in the modern ocean increased by more than a factor of 2 relative to the coupled model prescribed with glacial boundary conditions. In the model, N-loss processes respond faster to climate change than N_2 fixation. The two main effects are solubility/circulation changes that affect the ventilation of the suboxic zones where water column N-loss occur and sea level change that determines the area of shallow continental shelves where benthic N-loss is most abundant. N_2 fixation responds much slower in the model, which allows the oceanic nitrogen inventory to drift to a different level before a new equilibrium state is established. The model estimates that the size of marine nitrogen inventory in the modern ocean is at least 10% smaller compared to the last glacial maximum. But rather than simply following a unidirectional trajectory, the global warming of the deglacial transition was marked by widespread, millennial-timescale changes in the nitrogen cycle, as indicated by δ^{15}N records, that paralleled known changes in ocean circulation and climate. Our results confirm that the marine nitrogen cycle is highly sensitive to climate, and demonstrate the power of combining model results with a global array of sedimentary nitrogen isotope records in documenting its response.