Interactive comment on "Icehouse-greenhouse variations in marine denitrification" by T. J. Algeo et al.

Anonymous Referee #1
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General comments:

The manuscript by Algeo et al. presents a synthesized nitrogen isotope (d15N) record of marine sediments back to 660 Ma. The dataset includes 153 marine units that come from new analyses for this study, the authors' previous work and others' published data. Based on the synthesized record, the authors infer that greenhouse climate mode is characterized by lower d15N values while higher values in icehouse climates. After discussing various factors that could potentially affect sedimentary d15N values, including marine nitrogen cycle, diagenesis, terrestrial organic matter source and depositional setting, the authors conclude that the sedimentary d15N values largely reflect the nitrogen isotopic composition of seawater fixed nitrogen. Using a simple boxing model, the authors suggest a shift from sedimentary denitrification in greenhouse climate to water-column denitrification in icehouse climate, owing to global sea level changes. I believe that it is an excellent piece of work. For the first time, I have seen a nice, synthesized d15N record back to 660 Ma. Due to the nature of this work (sedimentary d15N values could be complicated by many factors), details need to be further addressed in future studies and potential alternative explanations might also exist. However, the authors appear to have presented a balanced, well-justified view. The authors provide a first-order view of d15N changes over the last 660 Ma, which could be linked to climate variation. I believe that it is an excellent contribution and strongly recommend its publication.

Reply to "general comments":

Thanks to the reviewer for these comments. We agree that the present work represents only a beginning in understanding long-term variation in the marine N cycle.

Specific comments:

1. The authors state that the marine nitrogen cycle is "linked to – and possibly a driver of – long-term climate change". It should be all right to state a linkage between the two as shown by the data. However, if the marine nitrogen cycle is possibly a driver of long-term climate change, how could this work, through emitting more N2O (which appears to me to be in an opposite sense), organic carbon deposition or something else? Could the authors elaborate this point a little further?

Reply to "specific comments":

1. Although linkage of the marine N cycle to long-term climate change is highly likely, the possibility of the marine N cycle serving as a driver of long-term climate change is merely speculative. Our intention in mentioning this possibility was to promote further consideration of the importance of the marine N cycle. However, there is no compelling evidence to support this possibility at present, and we ourselves are not specifically advocating it. Nonetheless, we will mention a few considerations about how the marine N cycle might drive long-term climate change. The principal driver of first-order climate variation is geotectonics (i.e., Wilson cycles of continental rifting and collision) and their influence on the latitudinal distribution of landmasses and the configuration of ocean basins and, hence, global ocean circulation. The critical issue is thus: What are the cause-and-effect pathways linking plate tectonics to global climate change? Past work has largely focused on the role of the carbon cycle, i.e., changes in atmospheric pCO_2 linked to mantle degassing, rates of uplift, and continental weathering, and changes in marine organic carbon burial rates as a function of oceanic circulation and seawater redox conditions. The marine N cycle is intimately connected to the latter process (i.e., marine organic carbon burial), but whether it is a passive responder to changes in carbon fluxes (as generally assumed) or an active control on such changes is uncertain. One mechanism by which the N cycle might be a driver is through switches between equatorial and polar sites of deepwater formation, with attendant effects on sites of deepwater nutrient upwelling. Even if the marine N cycle is a passive responder to carbon-cycle forcings, it may play an important role as an amplifier of climate change. For

example, enhanced N_2O production in low-oxygen regions of the ocean during extended intervals of climatic warming might serve as a positive climate feedback that promotes a bimodality of long-term climate conditions (i.e., greenhouse mode versus icehouse mode).

2. The authors suggest an expanded OMZ during icehouse climate as compared to greenhouse mode and recognize the different behavior of water-column denitrification changes at orbital (glacial-interglacial) vs. tectonic timescales. The authors stated “. . .repeated shifts in favor of water-column denitrification during the interglacial stages . . . have resulted in a sustained shift toward higher seawater d15N. . .”. How does this work? Obviously, denitrification changes at the two timescales are opposite. The long-term secular changes in seawater could explain time-averaged d15N, but cannot explain why d15N increased during interglacial stages.

2. Relative timescales are the key to understanding this apparent conundrum. Consider the possibility that, for a ~100-kyr glacial-interglacial cycle, each deglaciation event produces a positive shift x in the $\delta^{15}N$ of fixed nitrogen of *globally averaged* seawater, each glacial event produces a negative shift y, and $x > -y$. Through a succession of glacial-interglacial cycles, seawater fixed-nitrogen will develop a progressively more ^{15}N-enriched composition, even though the individual glacial epochs are characterized by lower $\delta^{15}N$ than the interglacial epochs. In this manner, icehouse-mode seawater will develop a more ^{15}N-enriched composition than greenhouse-mode seawater.