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EarthN_2O: Reconstructing the Dynamics of Atmospheric Nitrogen Oxides Across Geologic Time

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Nitrous oxide (N_2O), a trace gas produced as a biogeochemical byproduct and as technological waste, is a potent greenhouse gas (GHG) which can provide microbes with energy via metabolic pathways ancestral to oxygenic respiration. As such, N_2O and other nitrogen oxides (NO_x) could have exerted global influence on Earth's past climate, shifted the balance of Earth's nitrogen (N) cycle over time, and played an important role in the evolution of biogeochemical networks and the earliest metabolisms. Resolving the past abundances and effects of N_2O on the climate and biosphere could have broad implications for understanding the Earth's climatic and biogeochemical systems in the past, and thus provide better context for understanding modern climate instability. However, no continuous reconstruction of atmospheric or oceanic [N_2O] over Earth history is yet available. As such, the abundance and effects of N_2O in the Earth's past climatic and biogeochemical systems remain controversial.

To address this knowledge gap, we are developing a planetary N-cycle box model (EarthN_2O) to reconstruct steady-state N_2O and NO_x dynamics across deep time, from 4.5 Ga to the pre-industrial modern era (late Holocene). The biological and geochemical processes driving N_2O production and consumption are sensitive to spatiotemporal variations in temperature, pH, and redox conditions across Earth's surface history. Hence, we incorporate paleoclimatic and paleogeographic forcings into this model, along with simplified representations of redox-stratified marine environments, abiotic N_2O production in the Hadean atmosphere and in the Precambrian oceans, and emissions from the terrestrial biosphere. After resolving steady-state abundances of N_2O and NO_x in Earth's surface systems, EarthN_2O will estimate the radiative forcing contribution of N_2O to greenhouse warming over geologic time, allowing more thorough assessment of its role in modulating Earth's paleoclimate.

When finalized and tuned against pre-industrial records of atmospheric pN_2O, this model will also be applied to 1) evaluate the potential metabolic contributions of N_2O and NO_x to the early biosphere, 2) estimate the long-term effects of extreme anthropogenic nitrogen fixation on N_2O emissions, and 3) model N_2O dynamics under diverse global redox conditions to assess its capabilities as an atmospheric biosignature on terrestrial exoplanets.