EarthN: a new model of the Earth system nitrogen cycle

Benjamin W Johnson*[1,2], Colin Goldblatt[2]

*benjamin.w.johnson@colorado.edu, @TheFractnFactor, http://www.benwjohnson.com

[1] *University of Colorado at Boulder*

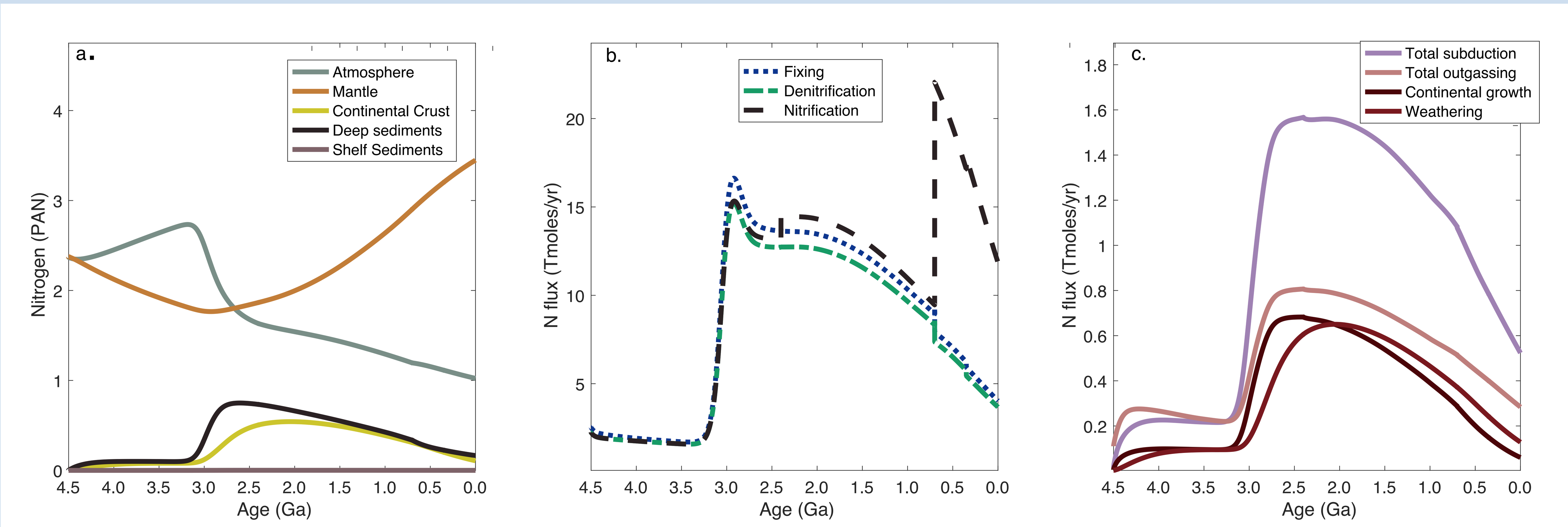
[2] *University of Victoria*

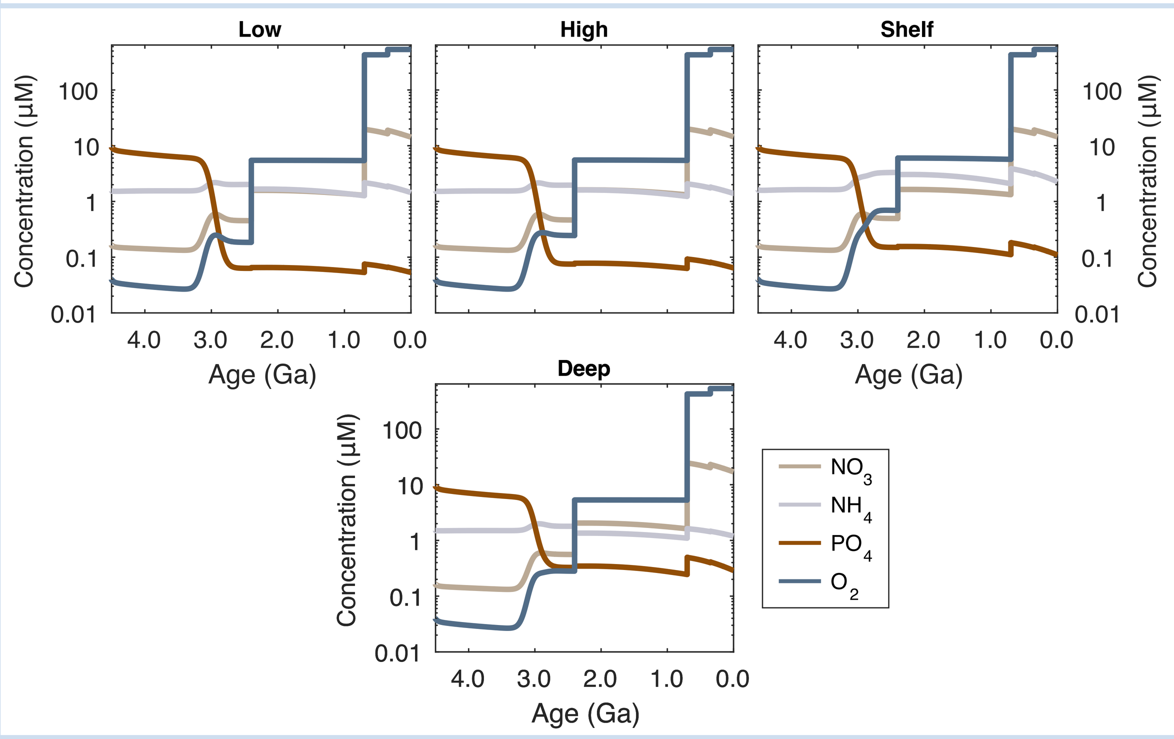
Earth System Nitrogen Cycle

- Nitrogen is the main component of the atmosphere, a key nutrient for organisms, and exerts control over climate via direct warming, as N_2O, and indirect effects, including pressure-broadening
- Previous models linked N to C, and typically only considered biologic or geologic fluxes in detail, focusing on sedimentary rocks. These studies suggest atmospheric mass steady over Earth history, which does not match new geochemical and physical paleobarometers
- New approach is to more completely include biologic and geologic fluxes, and link N behavior to PO_4 and O_2 abundance through time
- This approach is consistent with large-scale changes in atmospheric mass through time, up to 3 present atmospheric masses of nitrogen (1 PAN $= 4 \times 10^{18}$ kg N) supporting geochemical proxies that indicate atmospheric drawdown through time

Standard run results: atmospheric drawdown

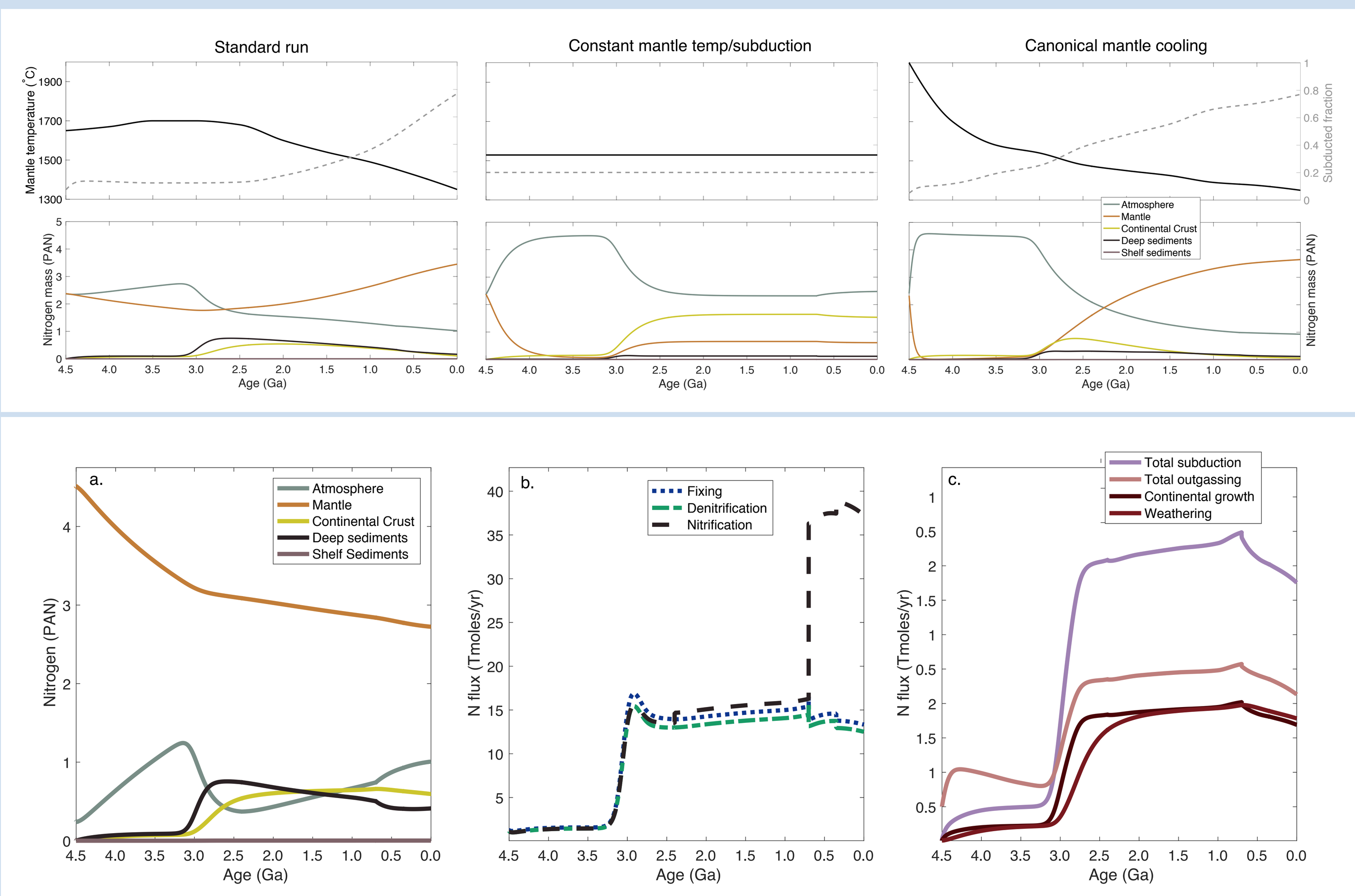
- 4.75 PAN total N, equal amounts starting in atmosphere and mantle
- Mantle cooling, subduction rate, crust production from Korenaga, 2010
- Oxygenic photosynthesis evolves at 2.8 Ga
- Hydrothermal alteration is fixed volume flow (5×10^{16} L yr-1)





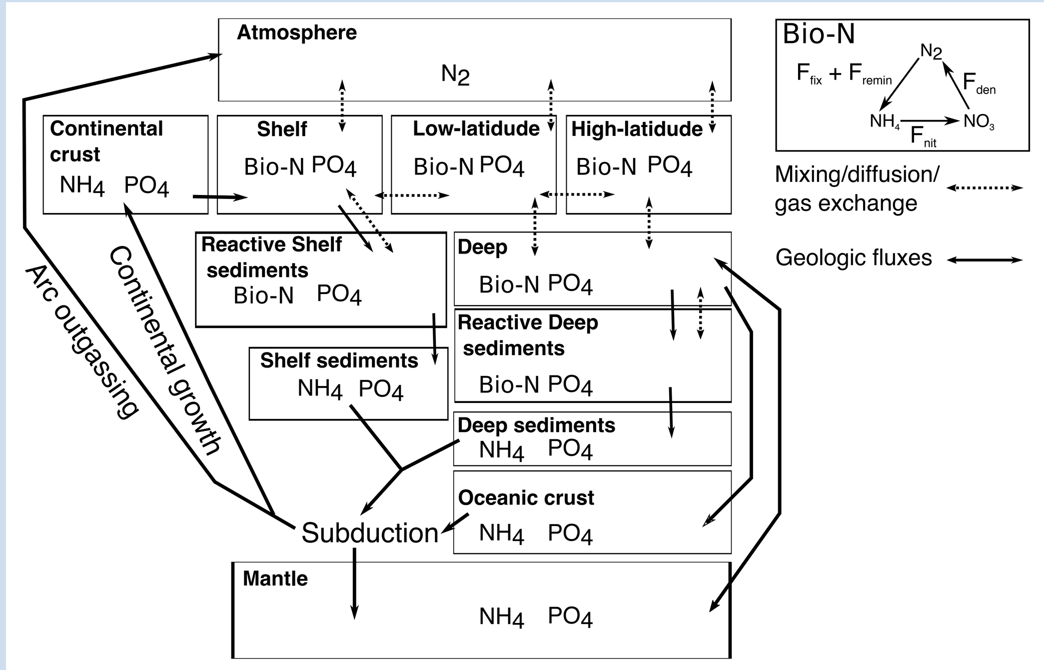
- Initial phase of atmospheric growth: high mantle T, low export production
- Drawdown to sediments when oxygenic photosynthesis evolves
- Continued drawdown to mantle and continental crust due to mantle cooling
- N speciation in ocean tightly linked to O_2 abundance, NH_4 and NO_3 ~equal in the Proterozoic
- Small O_2 oasis in late Archean shelf ocean

Model sensitivities: mantle cooling and low pN_2?

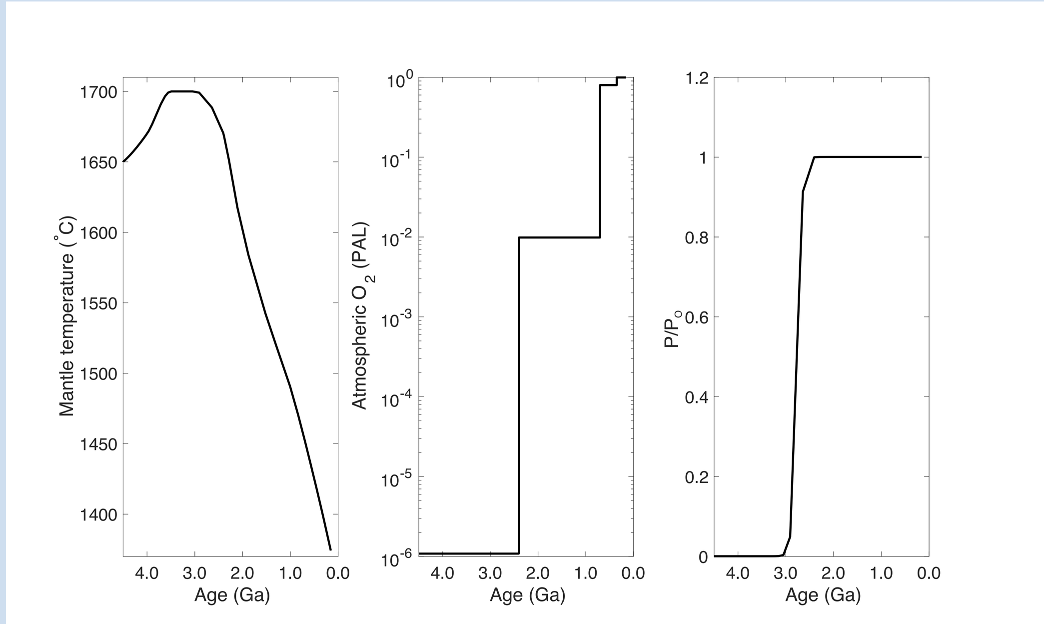


- Mantle temperature has strong control on atmospheric mass
- Large changes in N distribution possible, depending on mantle cooling history
- Highlights importance of mantle N cycle: strong relationship between solid Earth history and atmospheric evolution
- low pN_2 in Archean and Proterozoic only reproduced in model with very specific conditions: low starting atmospheric mass, sluggish upwelling (5 Sv), and constant and inefficient subduction (10%)

EarthN model setup

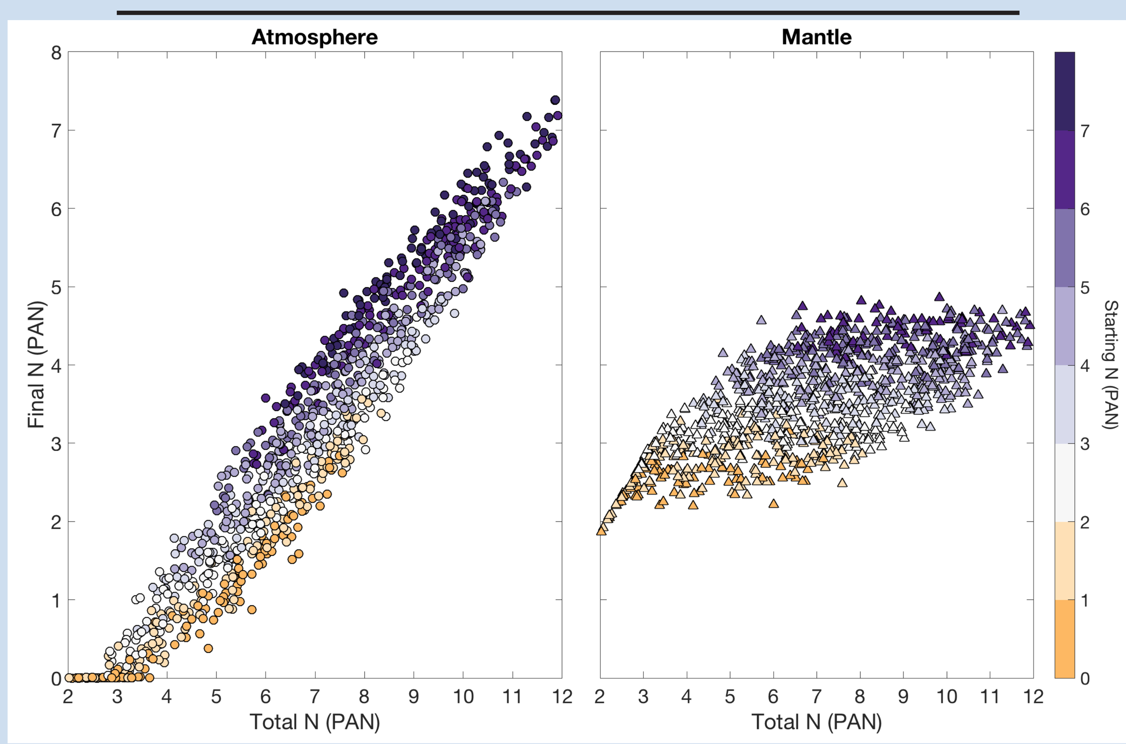


- Biologic fluxes: export production from fixed N and newly-fixed N (F_{fix}), remineralization (F_{remin}), nitrification (F_{nit}), and denitrification (F_{den}). Export production occurs shallow ocean (Shelf, high-latitude, low-latitude), all nitrogen fluxes occur in all ocean boxes and upper sediments (i.e., reactive shelf and deep sediments)
- Geologic fluxes: include burial, subduction, outgassing, hydrothermal alteration of ocean crust, and continental weathering
  - Subduction efficiency is linked to mantle temperature: hot mantle ⇒ more N returns to atmosphere at subduction zones, cooler mantle ⇒ more N sequestered to mantle
  - Remineralization and production efficiency linked to O_2: oxygenic photosynthesis is more effective at primary production, deep water O_2 leads to more efficient remineralization
- Run model for 4.5 Gyr
- Model is driven by mantle cooling, atmospheric O_2, and export production (P/P_O, where P_O is modern efficiency) (below)



Monte Carlo results

Parameter	Range
Upwelling	0.16–16 Sv
Ox. photo.	2.4-3 Ga
Hydrothermal flow	0.5-50$\times 10^{16}$ L yr^{-1}
Total N	2-12 PAN
Initial atm.	0-100%



Results from 1000 runs. Total N has strong control on final (after 4.5 Gyr) atmospheric mass, independent of starting atmospheric mass. At low total N, N-fixing and subduction is larger than outgassing, so the mantle contains the majority of N. At high total N, N-fixing is too low (PO_4−limited) to draw down massive atmosphere.

Conclusions

- By linking with PO_4, we show that this nutrient interacts with N to control N distribution
- Incorporating geologic fluxes (sedimentation, subduction) provides new depth
- Planetary atmospheres with N_2 can vary substantially over time in the presence of life with direct implications for sustained habitability
- Total planetary N has strong control on distribution, but more detailed mantle cycle needed
- Model as constructed can make predictions, including atmospheric mass, fluxes, and eventually isotopic record