Evolution of the polar outflow from the Earth's cusps

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Motivation for the study

Airapetian et al. 2016
Evolution of the Sun and its XUV (X-ray + EUV) output

Tu et al. 2015
Evolution of the Sun and its XUV (X-ray + EUV) output

Tu et al. 2015

Mid-Archean and later
Evolution of the solar wind

The evolution of the solar wind also depends on the solar rotation evolution

Johnstone et al. 2015
Evolution of the solar wind

The evolution of the solar wind also depends on the solar rotation evolution

Johnstone et al. 2015
Evolution of the Earth's dynamo

Magnetic moment evolution following Biggin et al. 2015
Evolution of the Earth's atmosphere

Johnstone et al. 2018
Upper atmosphere structure

Kislyakova et al. submitted

3.0 Gigayears ago
2.5 Gigayears ago
Present-day
Evolution of the polar outflow

The outflow is assumed to be source limited.

We assume the modern-day composition of the atmosphere.

![Graph showing the evolution of escape rates over geologic time.](image-url)
The Great Oxydation Event (GOE) and the polar outflow

Simulation 2.5 Ga with modern composition: $O^+$ escape = $1.6 \times 10^{27}$ s$^{-1}$, $N^+$ escape = $5.6 \times 10^{26}$ s$^{-1}$

Simulation 2.5 Ga with 1% oxygen: $O^+$ escape = $2.0 \times 10^{26}$ s$^{-1}$, $N^+$ escape = $2.9 \times 10^{27}$ s$^{-1}$
Conclusions

• Polar outflow of the nitrogen ions three gigayears ago increases by two orders of magnitude compared to its present value.

• Polar outflow of oxygen ions from the Earth’s open field line regions varies greatly depending on the oxygen mixing ratio.

• Polar outflow escape is governed primarily by the evolution of the solar short-wavelength radiation and the atmosphere’s composition.

→ Kislyakova et al., JGR, under review