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Evolution of the Earth's polar wind escape from mid-Archean to present

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The evolution of habitable conditions on Earth is tightly connected to the evolution of its atmosphere which, in turn, is strongly influenced by atmospheric escape. We investigate the evolution of the the polar wind outflow from the magnetic cusps which is the dominant escape mechanism on the Earth. We perform Direct Simulation Monte Carlo (DSMC) simulations and estimate the upper limits on escape rates from the Earth's cusps starting from three gigayears ago (Ga) to present assuming the present-day composition of the atmosphere. We perform one additional simulation with a lower mixing ratio of oxygen of 1% to account for the conditions shortly after the Great Oxydation Event (GOE). We account for the evolution of the magnetic field of the Earth by adjusting the polar opening angle and the location of the magnetosphere's substellar point.

Our results present an upper limit on the escape rates, but they indicate that polar wind escape rates for nitrogen and oxygen ions were likely much higher in the past. We estimate the maximum total loss rates due to polar wind of 2.0×10^{18} kg and 5.2×10^{17} kg for oxygen and nitrogen, respectively. According to our results, the main factors that governed the polar wind outflow in the considered time period are the evolution of the XUV radiation of the Sun and the atmosphere's composition. The evolution of the Earth's magnetic field plays a less important role. We conclude that although the atmosphere with the present-day composition can survive the escape due to polar wind outflow, a higher level of CO_2 between 3.0 and 2.0 Ga is likely necessary to reduce the escape.