N⁺: Gatekeepers of Ionospheric Outflow

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ABSTRACT

The escape of heavy ions from the Earth atmosphere is facilitated by energization and transport mechanisms, including photoionization, electron precipitation, ion-electron-neutral chemistry and collisions. Numerous studies considered the outflow of O^+ ions only, but ignored the observational record of outflowing N^+ ions. Single field line numerical simulations using 7iPWOM showed that the inclusion of N^+ in the polar wind model can largely improve the polar wind solution under various solar activities, seasons and solar zenith angles. We examined the overall polar wind outflow flux predicted by the 7iPWOM from several hundred kms altitude to few Earth radii by running the multi-line simulations and comparing with the multi-line polar wind solution without the inclusion of N^+. Numerical experiments suggest that N^+ is a significant ion species in the polar ionosphere. Its presence largely reduces the O^+ outflow flux by two order of magnitudes, and change the structure of ions temperature.

HELIOPHYSICS RESEARCH & APPLICATIONS

N⁺: Important Ion Species in the Polar Wind

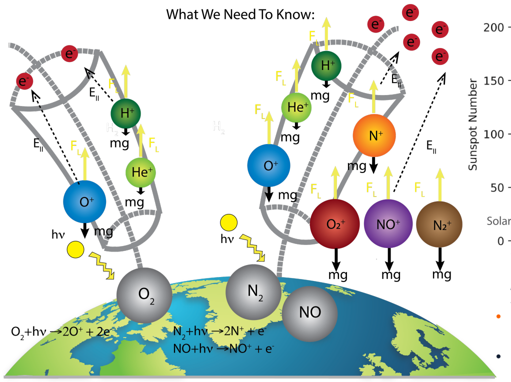
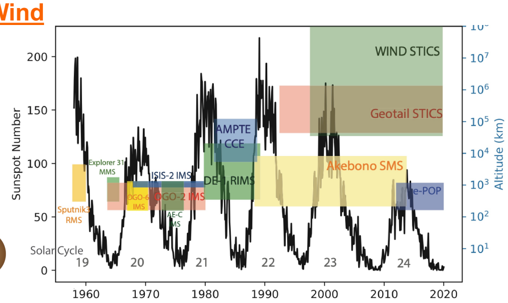


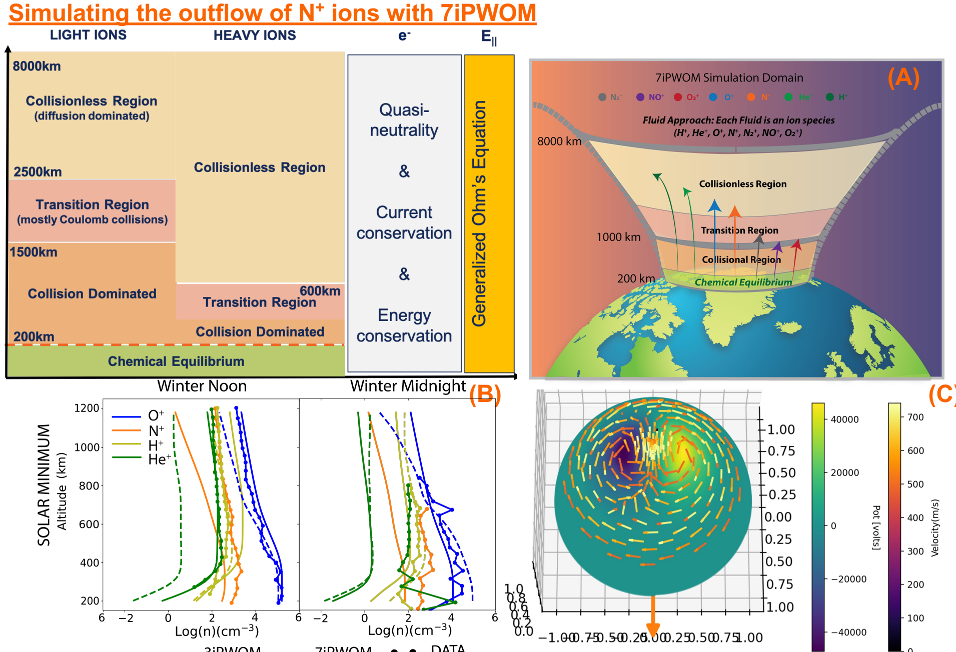
Diagram showing 3 ion vs. 7 ion view of polar wind outflow (Lin & Ilie, [2021], submitted)



Measurements of N⁺ in the Earth's magnetosphere and ionosphere system from the 60 years (Ilie et al., 2021, submitted)

- **What is the role of N⁺ ions in the overall polar wind condition?**
- N^+ has been observed at altitudes starting from few hundred kms to several Earth radii in the last 60 years, from missions covering both solar maximum and solar minimum cycles.

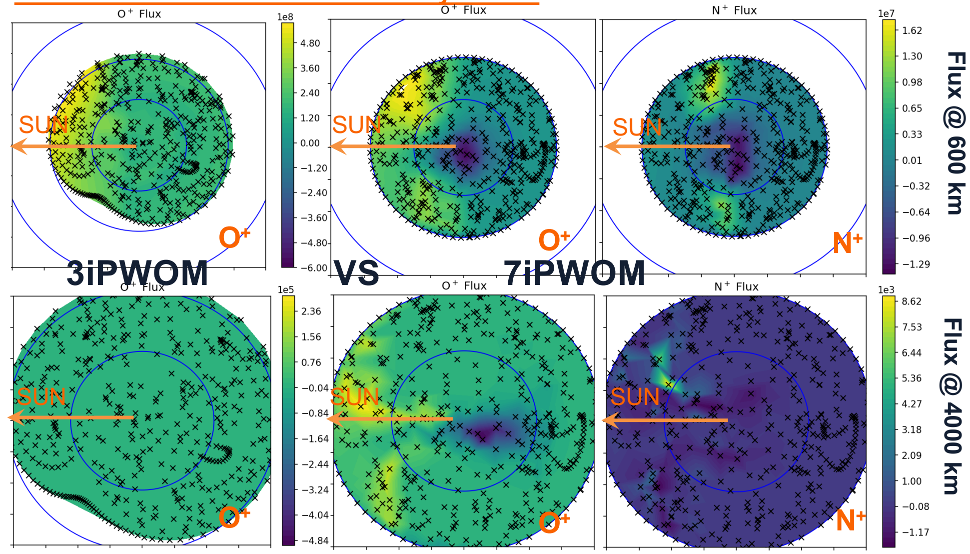
Simulating the outflow of N⁺ ions with 7iPWOM



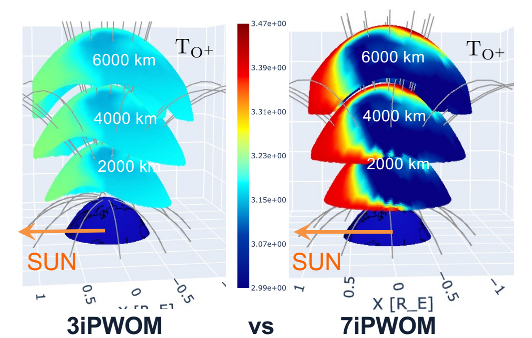
(A) Diagram of 7iPWOM; (B) The comparison of data (dotted line, OGO-6), 3iPWOM (dashed line) and 7iPWOM (solid line) under solar minimum (F10.7=100) winter noon and midnight (Lin et al., 2020, GRL); (C) Electrodynamic configuration of (3i)PWOM and 7iPWOM

- The Seven Ion Polar Wind Outflow Model (7iPWOM) includes expanded schemes for suprathermal electron (SE) production and ion-electron-neutral chemistry and collisions.
- The convection of field lines is determined by ionospheric electrodynamics , with the convection $\boldsymbol{u} = -(\boldsymbol{E} \times \boldsymbol{B})/B^2$.
- Simulation: 500 field lines (3i)PWOM vs. 7iPWOM during the solar minimum spring.

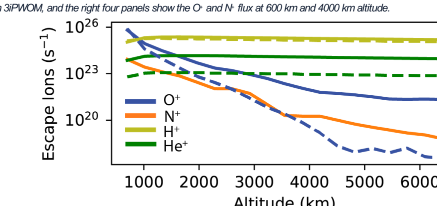
3iPWOM vs. 7iPWOM: Predicted Heavy Ouflow



Solar Minimum Spring: The left two panels show the O⁺ flux at 600 km altitude (upper) and 4000 km altitude (lower) from 3iPWOM, and the right four panels show the O⁺ and N⁺ flux at 600 km and 4000 km altitude.



Comparison of temperature of O⁺ ions (T_{O^+}) between 3iPWOM (left) and 7iPWOM (right) at slices of 2000, 4000, and 6000 km altitudes during the solar minimum spring.



*Solar Min Spring: Compare the escape H⁺ (light green), He⁺ (dark green), O⁺ (blue) and N⁺ (orange) ions between 3iPWOM (dashed line) and 7iPWOM (solid line) with the altitude from 600 to 6400 km. (Escape ions = ∑Ions Flux*Flux Area)*

- The spatial distributions of O^+ ions are different due to the extra Note that terms of SE and chemical reactions in the 7iPWOM. N^+ ion fluxes are constantly one order of magnitude less than O^+ at low altitude region.
- The number of escape O^+ increases orders of magnitude in the high-altitude region, possibly due to frictional heating terms from N^+ (causing higher T_{O^+}).

CONCLUSIONS

- The presence of N^+ in the polar wind will redistribute the ion composition by altering the SE production and chemical reactions.
- The escape rates of O^+ and He^+ at 4000 km altitude both increase by orders of magnitude, possibly due to the expanded SE production and the additional frictional heating terms from the collision with N^+ ions.

ACKNOWLEDGEMENTS

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