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# Solar Proton Events – Effects on Middle Atmospheric Hydrogen and Nitrogen Species


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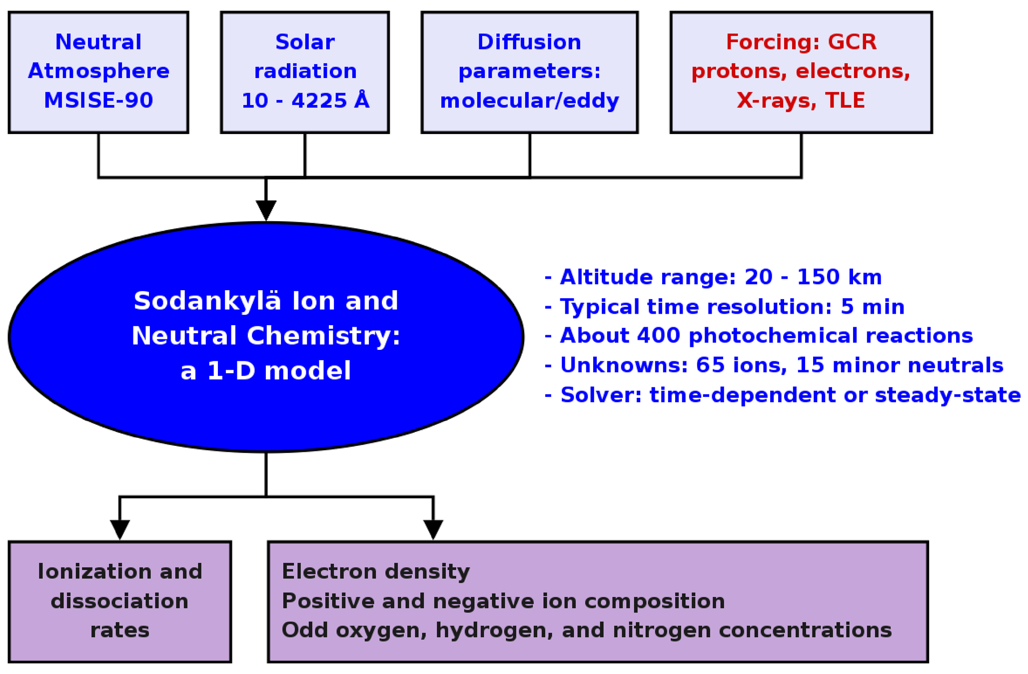
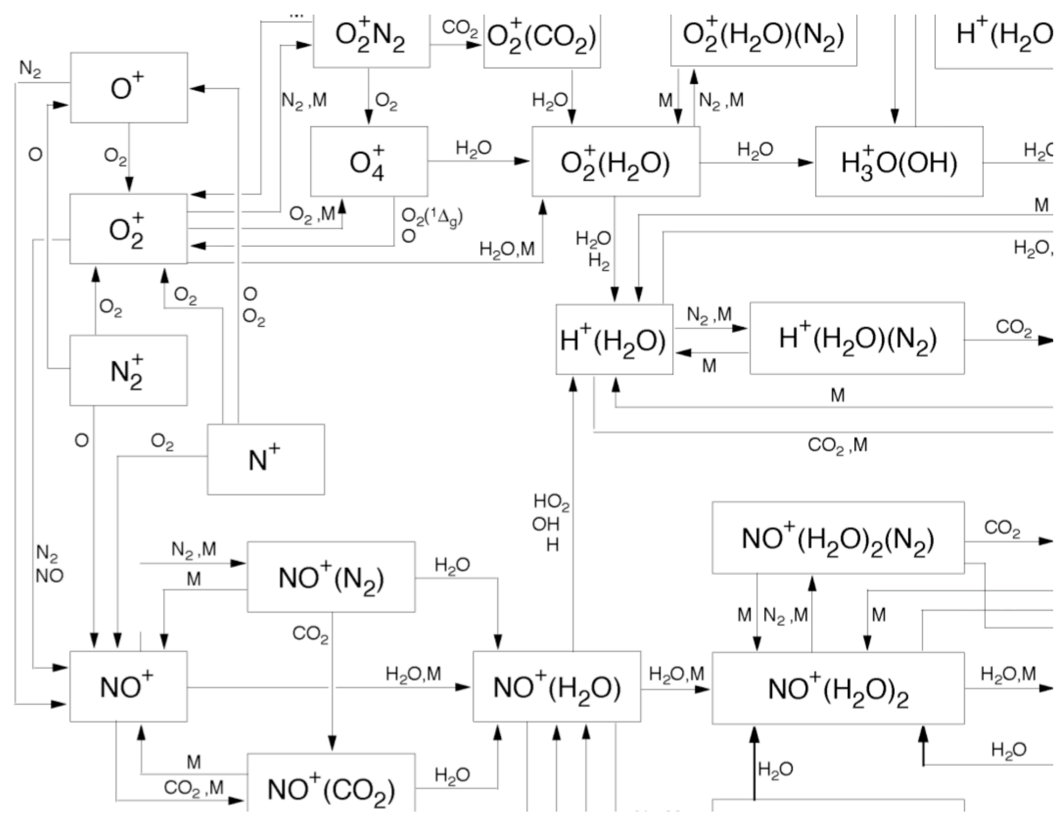
**Abstract.** In the middle atmosphere, enhanced ionization by precipitating particles leads to changes in minor neutral composition through ion chemistry. For example, nitrogen and water vapor molecules are dissociated, and odd hydrogen ($HO_x$ = H + OH + $HO_2$) and odd nitrogen ($NO_x$ = N + NO + $NO_2$) species are produced. Increase in $HO_x$ and $NO_x$ concentrations can then boost the catalytic reaction cycles that destroy ozone.

In this paper, we utilize the Sodankylä Ion and Neutral chemistry model (SIC), which combines ion and neutral chemistry for particle precipitation studies. Based on an analysis of the SIC chemistry, we demonstrate how positive ion chemistry produces $NO_x$ and $HO_x$, while negative ion chemistry redistributes $NO_y$ species by converting $NO_x$ and $N_2O_5$ to $HNO_3$ and $NO_3$). Recent SIC results on OH and $HNO_3$ during solar proton events are presented, including comparisons with satellite instruments. We put forward an improved parameterization, which takes into account both positive and negative ion chemistry and can be used to model the effects of particle precipitation.


## THE SIC MODEL



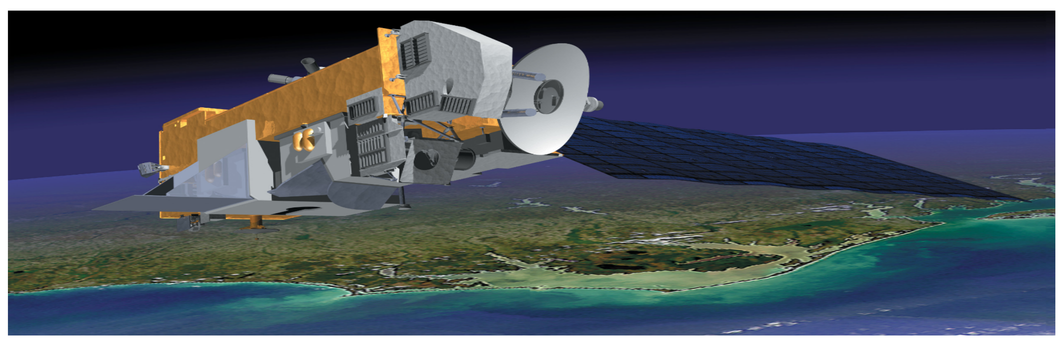

**Above:** SIC model input/output diagram. **Below:** part of the SIC positive ion scheme, and two examples of reaction pathways leading to H, OH, and $HNO_3$ production.



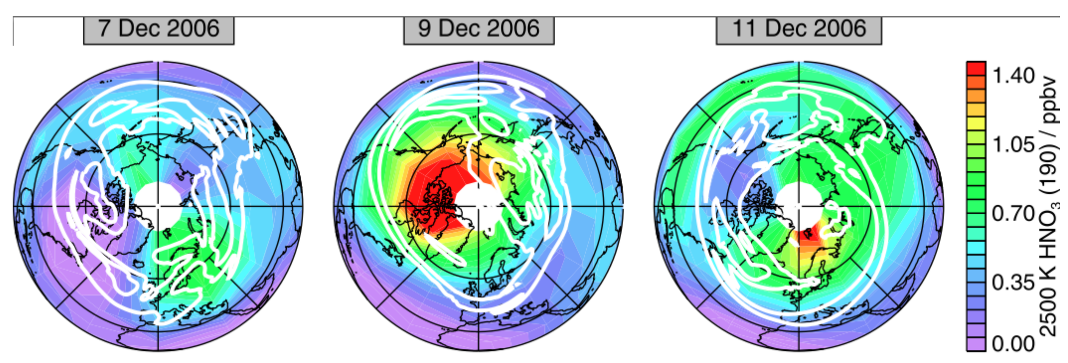
$$
\begin{aligned}
N_2 + p^+(E) &\rightarrow N_2^+ + e^- + p^+(E-\Delta E)\\
N_2^+ + O_2 &\rightarrow O_2^+ + N_2\\
O_2^+ + O_2 + M &\rightarrow O_4^+ + M\\
O_4^+ + H_2O &\rightarrow O_2^+(H_2O) + O_2\\
&\dots\\
O_2^+(H_2O)_2 + H_2O &\rightarrow H_3O^+(OH)H_2O + O_2\\
H_3O^+(OH)H_2O + H_2O &\rightarrow H^+(H_2O)_3 + \mathbf{OH}\\
H^+(H_2O)_3 + H_2O + M &\rightarrow H^+(H_2O)_4 + M\\
H^+(H_2O)_4 + e^- &\rightarrow \mathbf{H} + 4H_2O\\
--- &\quad ---\\
\mathbf{Net}: H_2O &\rightarrow OH + H
\end{aligned}
$$

$$
\begin{aligned}
N_2 + p^+(E) &\rightarrow N_2^+ + e^- + p^+(E-\Delta E)\\
O_2 + O_2 + e^- &\rightarrow O_2^- + O_2\\
O_2^- + O_3 &\rightarrow O_3^- + O_2\\
O_3^- + CO_2 &\rightarrow CO_3^- + O_2\\
CO_3^- + NO_2 &\rightarrow NO_3^- + CO_2\\
NO_3^- + H_2O + M &\rightarrow NO_3^-(H_2O) + M\\
NO_3^-(H_2O) + HNO_3 &\rightarrow NO_3^-(HNO_3) + H_2O\\
NO_3^-(HNO_3) + \mathbf{H^+(H_2O)_4} &\rightarrow \mathbf{HNO_3} + HNO_3 + 4H_2O\\
--- &\quad ---\\
\mathbf{Net}: \mathbf{H_2O} + O_3 + NO_2 &\rightarrow \mathbf{OH} + HNO_3 + O_2
\end{aligned}
$$

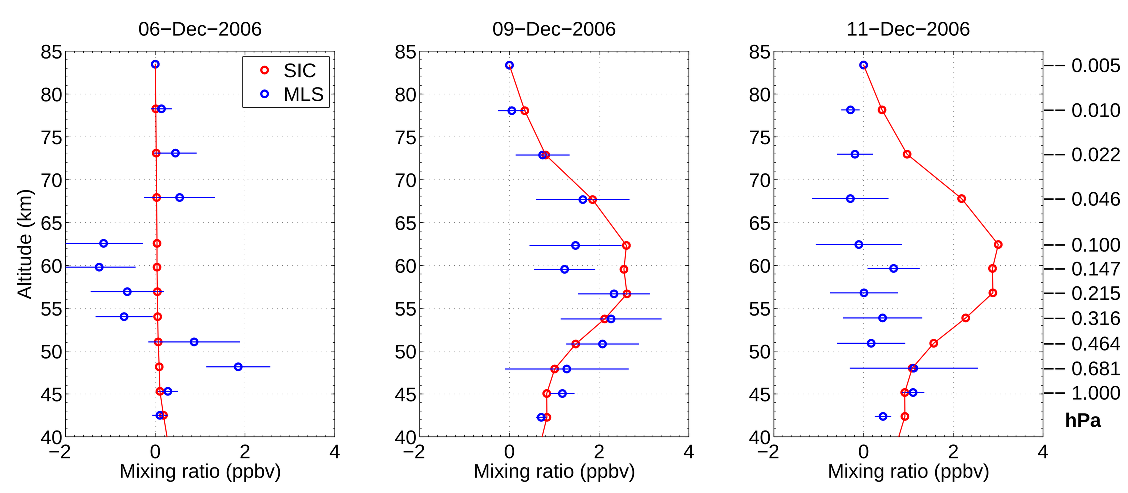
## MODEL-SATELLITE COMPARISON



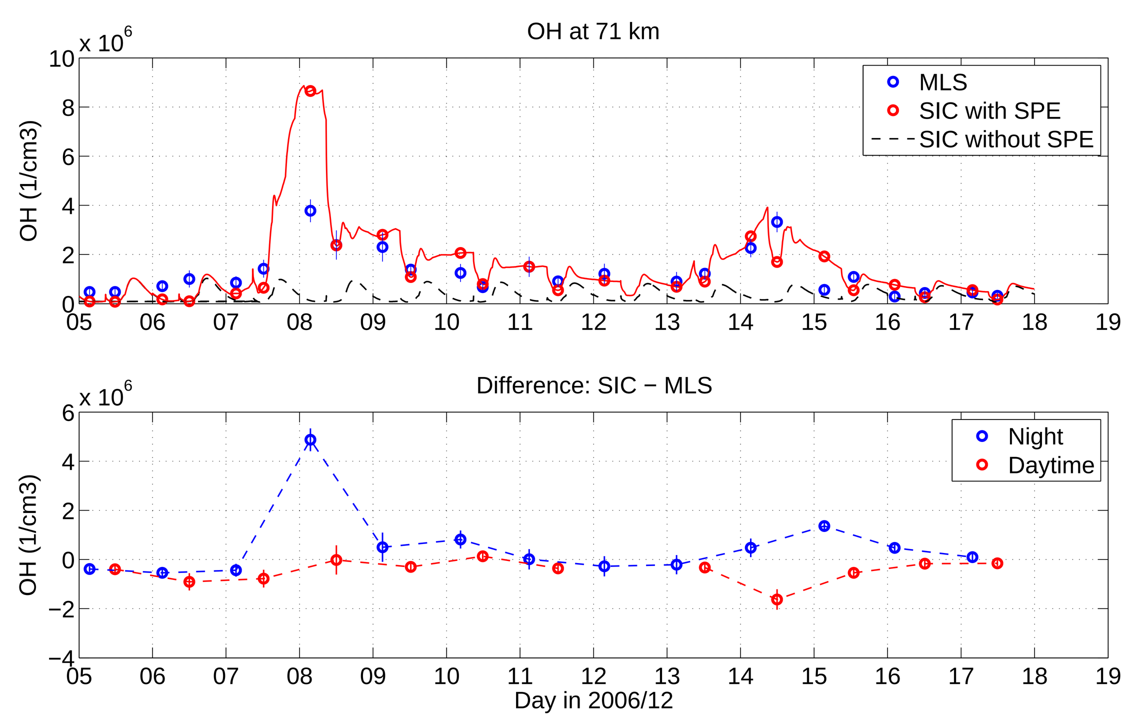
**Above:** Aura satellite on orbit with Microwave Limb Sounder (MLS) on board. **Below:** NH polar $HNO_3$ from MLS. Note the increase during the solar proton event (middle panel).

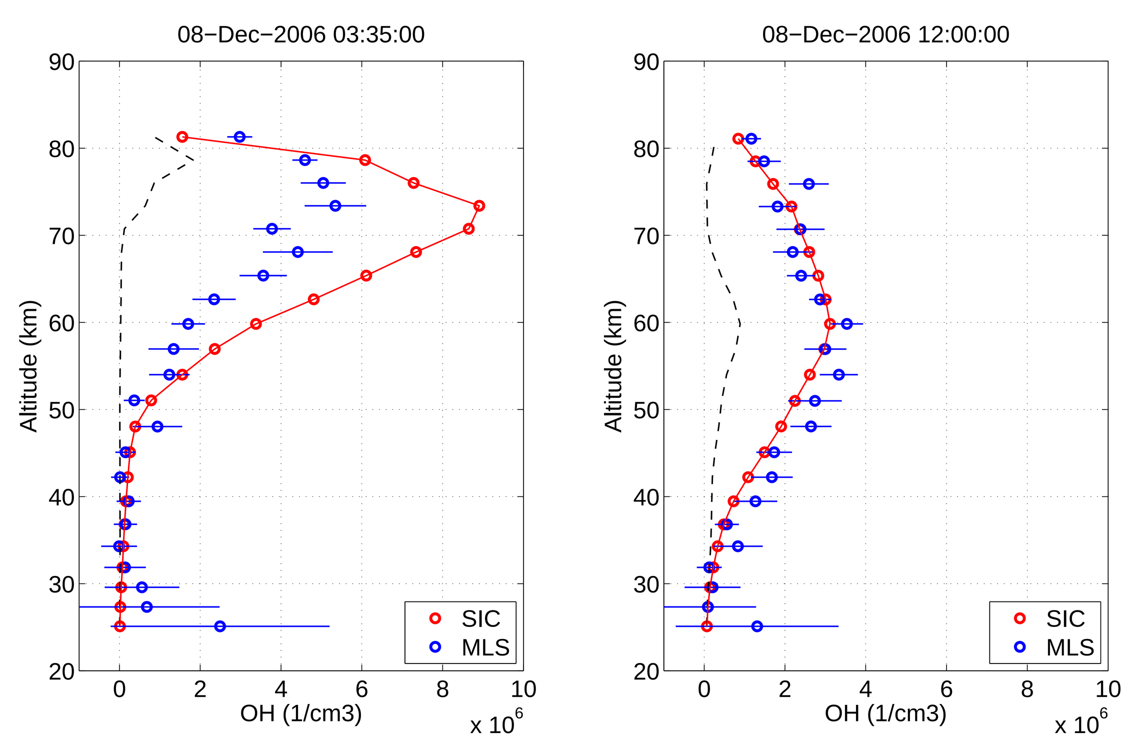



**Below:** SIC-MLS comparison of $HNO_3$ at 80°N/75°W.




**Below:** SIC-MLS comparison of OH in December 2006. Note the good agreement in daytime. SIC overestimates OH at nighttime on Days 8 and 15.

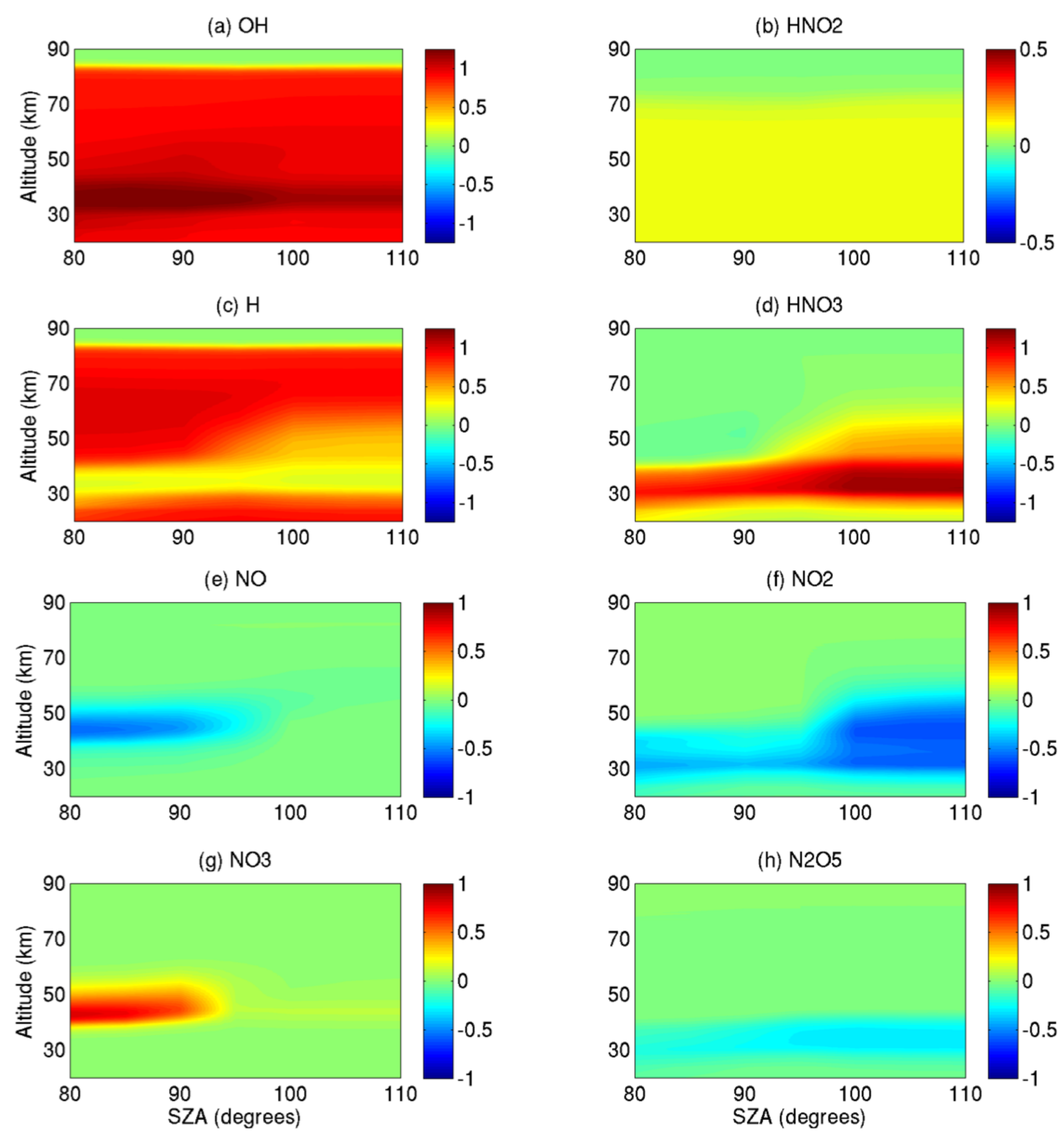



## ION CHEMISTRY PARAMETERIZATION

$$P/Q = \frac{(P_{spe} - L_{spe}) - (P_{ref} - L_{ref})}{Q}$$

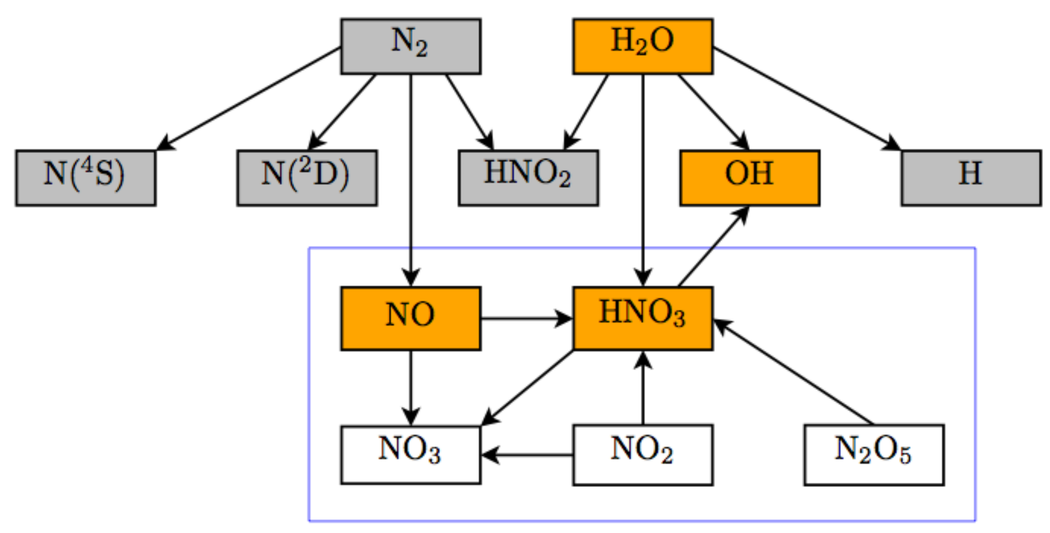
**Above:** The production rates of, e.g., OH and $HNO_3$ can be calculated from SIC model results considering production ($P$) and loss ($L$) processes. **Below:** Examples of P/Q number, NH, January, Q = 100 $cm^{-3}s^{-1}$.




**Below:** Example of P/Q tables, numbers given with respect to altitude, ionization rate, solar zenith angle, and season of year.

| Q | $10^1$ | $10^2$ | $10^3$ | $10^4$ | $10^5$ | $10^1$ | $10^2$ | $10^3$ | $10^4$ | $10^5$ | $10^1$ | $10^2$ | $10^3$ | $10^4$ | $10^5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| km | | SZA | ≤ | 90° | | | SZA | = | 95° | | | SZA | ≥ | 100° | |
| 90 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 |
| 85 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 | +0.00 |
| 80 | +0.00 | +0.00 | +0.00 | +0.00 | −0.01 | +0.00 | +0.00 | +0.00 | +0.00 | −0.01 | +0.00 | +0.01 | +0.01 | −0.00 | −0.01 |
| 75 | −0.00 | −0.00 | −0.00 | −0.00 | −0.01 | −0.00 | −0.00 | −0.00 | −0.00 | −0.01 | +0.00 | +0.01 | +0.01 | +0.01 | −0.00 |
| 70 | −0.00 | −0.00 | −0.00 | −0.00 | −0.01 | +0.00 | +0.00 | +0.00 | −0.00 | −0.01 | +0.03 | +0.02 | +0.04 | +0.04 | +0.02 |
| 65 | −0.00 | −0.00 | −0.00 | −0.00 | −0.00 | +0.02 | +0.01 | +0.01 | +0.02 | +0.01 | +0.16 | +0.10 | +0.12 | +0.12 | +0.05 |
| 60 | −0.01 | −0.00 | −0.01 | +0.00 | +0.03 | +0.08 | +0.04 | +0.04 | +0.08 | +0.07 | +0.38 | +0.23 | +0.20 | +0.23 | +0.15 |
| 55 | −0.02 | −0.01 | −0.01 | +0.02 | +0.10 | +0.20 | +0.14 | +0.10 | +0.15 | +0.17 | +0.54 | +0.38 | +0.27 | +0.32 | +0.29 |
| 50 | −0.06 | −0.02 | −0.00 | +0.05 | +0.19 | +0.35 | +0.28 | +0.19 | +0.21 | +0.27 | +0.57 | +0.49 | +0.34 | +0.35 | +0.42 |
| 45 | −0.12 | −0.04 | +0.03 | +0.12 | +0.28 | +0.50 | +0.40 | +0.29 | +0.27 | +0.35 | +0.65 | +0.52 | +0.40 | +0.38 | +0.48 |
| 40 | +0.27 | +0.23 | +0.19 | +0.22 | +0.34 | +0.55 | +0.49 | +0.37 | +0.32 | +0.40 | +0.66 | +0.59 | +0.46 | +0.40 | +0.50 |
| 35 | +0.42 | +0.39 | +0.34 | +0.29 | +0.35 | +0.52 | +0.49 | +0.43 | +0.37 | +0.41 | +0.67 | +0.64 | +0.56 | +0.49 | +0.54 |
| 30 | +0.41 | +0.38 | +0.34 | +0.30 | +0.32 | +0.53 | +0.50 | +0.44 | +0.37 | +0.39 | +0.71 | +0.68 | +0.60 | +0.50 | +0.49 |
| 25 | +0.36 | +0.34 | +0.28 | +0.23 | +0.24 | +0.49 | +0.47 | +0.38 | +0.29 | +0.29 | +0.70 | +0.65 | +0.54 | +0.37 | +0.35 |
| 20 | +0.34 | +0.31 | +0.22 | +0.16 | +0.15 | +0.43 | +0.38 | +0.27 | +0.17 | +0.16 | +0.59 | +0.50 | +0.33 | +0.17 | +0.16 |

**Below:** A diagram of hydrogen and nitrogen conversions due to ionic reactions. The species in the gray boxes are affected by positive ion chemistry, while $NO_y$ redistribution by negative ion chemistry affects the species inside the blue box. NO, $HNO_3$, and $H_2O$ are directly affected by both positive and negative ion chemistry. Note that all-neutral reactions, e.g. production of NO from N($^2$D), are not included in the diagram.

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