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Mesospheric OH response to the impact of radiation belt electrons

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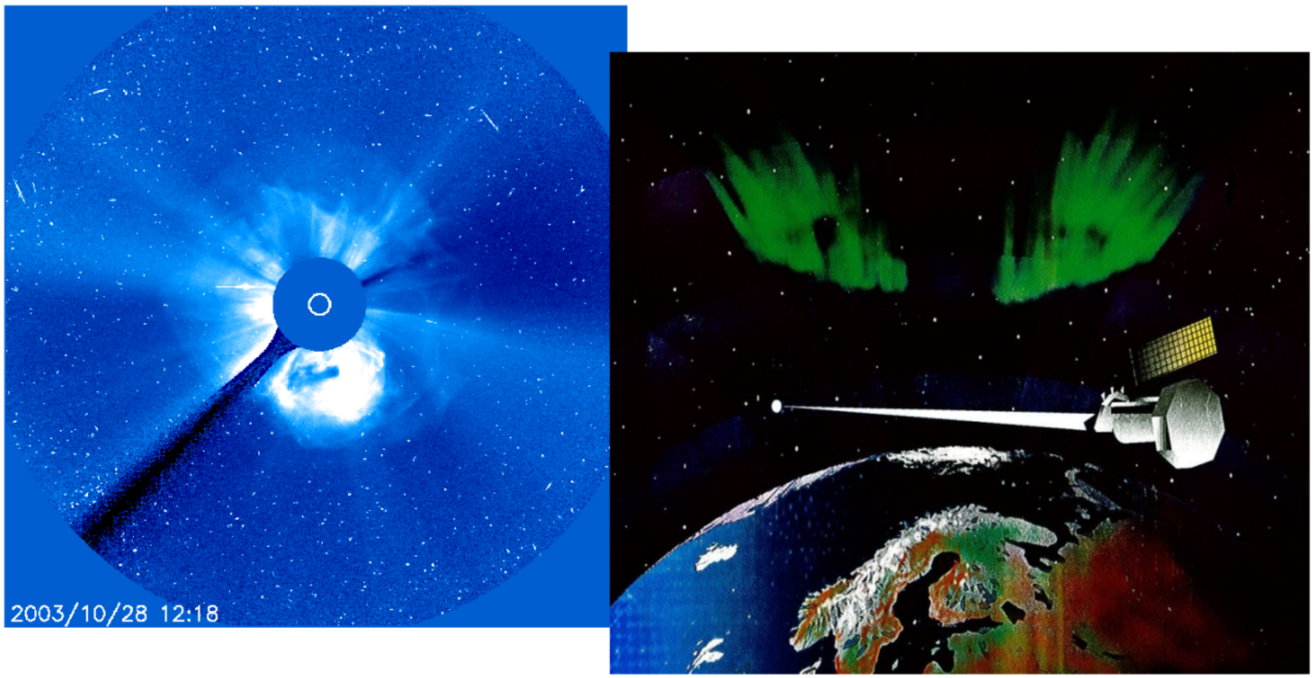
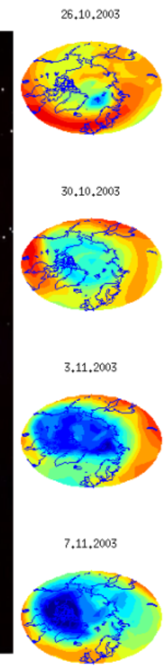
Solar energetic particle precipitation (EPP)

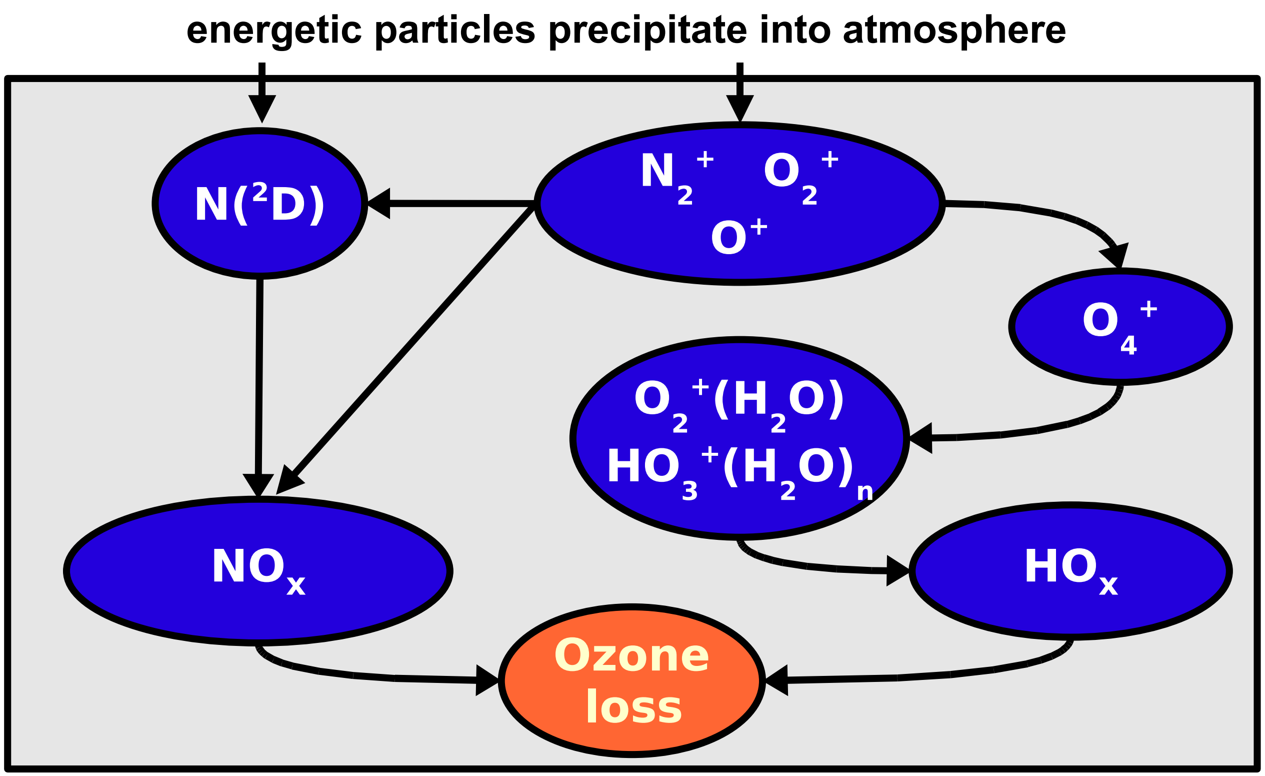




Earth's magnetic field directs charged particles into polar regions

EPP affects both ionosphere and middle atmosphere

Effects of energetic particle precipitation (EPP)



Ozone connects to temperature and dynamics

Mesospheric odd hydrogen: indicator of EPP

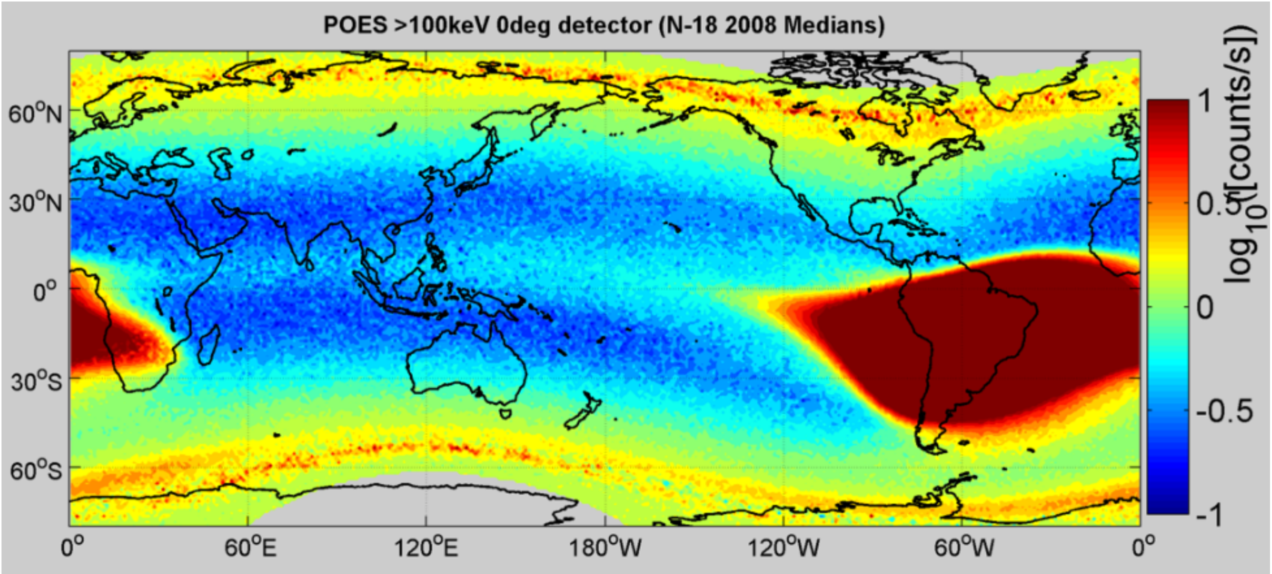
- nighttime HO_x (= H + OH + HO_2) concentration is relatively low.
  $\Longrightarrow$ It can be enhanced by moderate EPP forcing.

- HO_x has a relatively short chemical lifetime (hours) below $\approx$ 80 km.
  $\Longrightarrow$ Returns quickly to normal values after EPP forcing stops.

Odd hydrogen follows closely
increases and decreases of EPP forcing

- In the case of major solar proton events, HO_x increases are relatively easy to detect due to the large fluxes and polar cap coverage of the forcing.

Role of electron precipitation below 80 km



- Compared to solar proton events, electron precipitation typically has smaller fluxes, more temporal variability, and it affects more restricted latitude regions.
- Electron flux observations are not always straight forward to use in atmospheric modeling.

$\Longrightarrow$ It is not clear how big the direct effect of electron precipitation is.

In the present work

- We study the connection between precipitating electrons (measured in the radiation belts by MEPED/POES) and mesospheric OH observed by MLS/Aura.

- We look for

  1) OH increases in high-precipitation cases, e.g. March 2005.

  2) signatures of electron precipitation in OH during years 2004–2009.

- We ask:

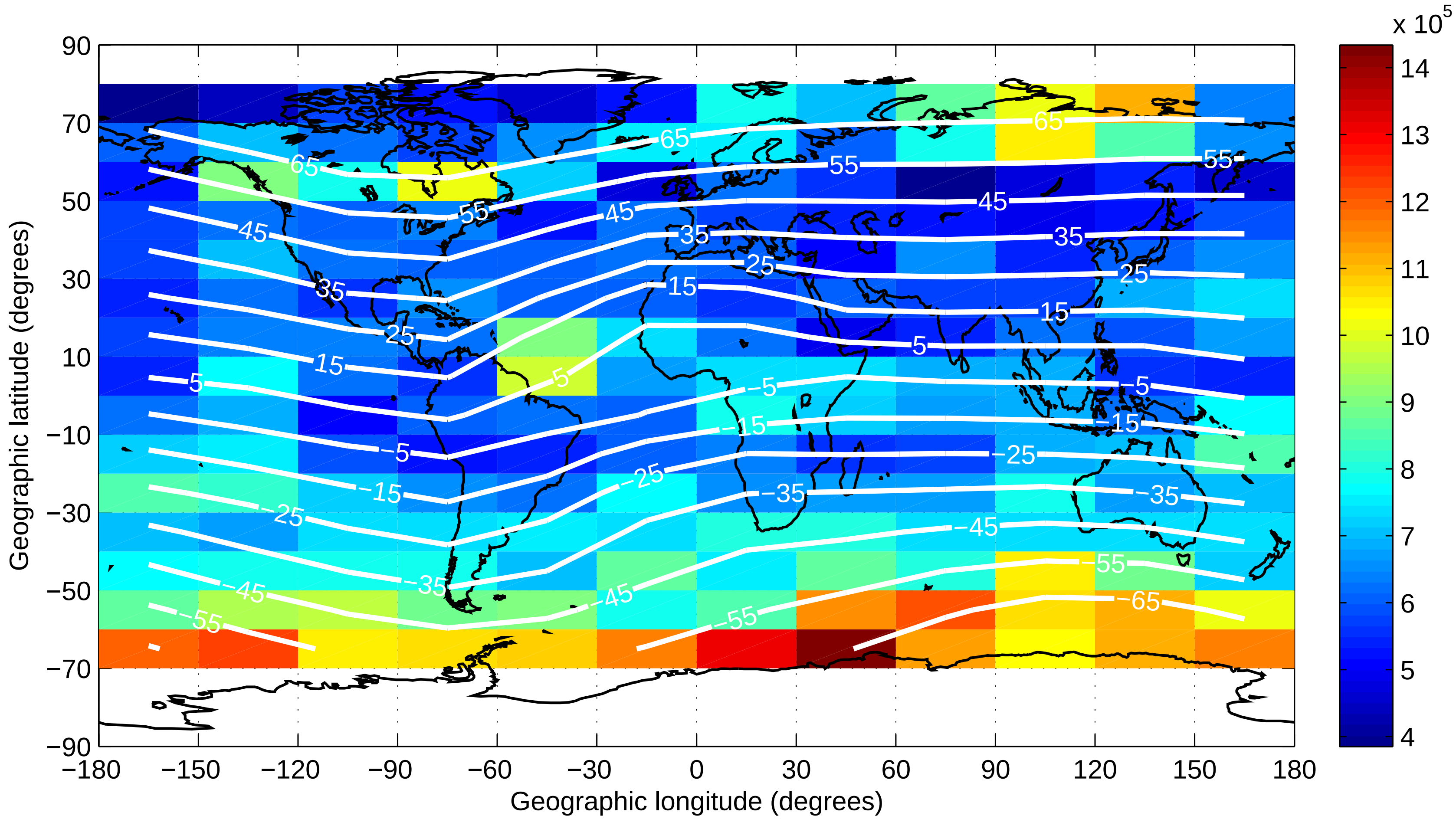
  1) is electron precipitation causing measurable changes in OH?

  2) how often is OH affected by electron precipitation?

  3) can we model OH and ozone changes caused by electrons?

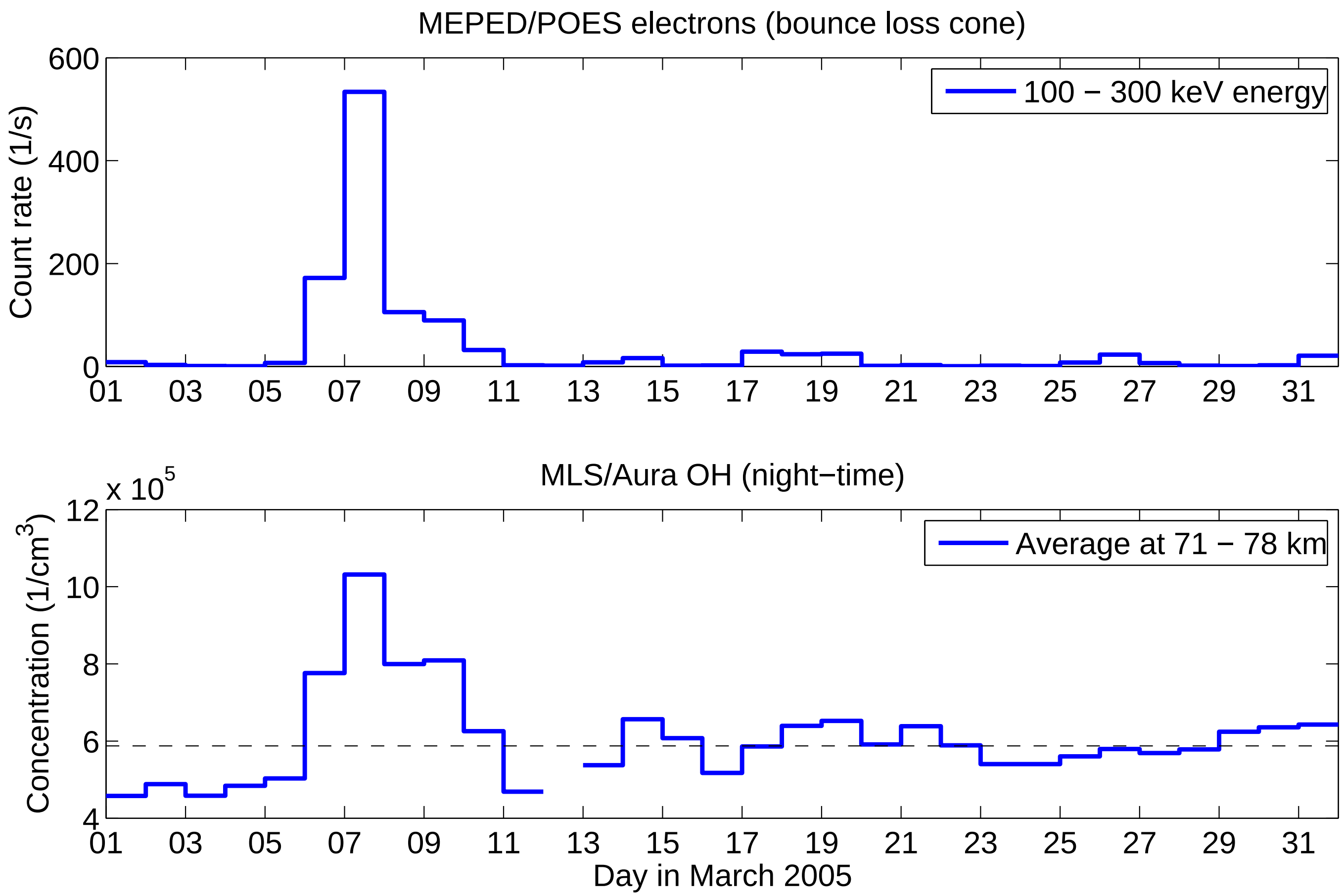
Mean nighttime OH, March 5–10, 2005

MLS/Aura, Altitudes 71 – 78 km, Units: cm^{-3}



Electron precipitation and OH in March 2005

Magnetic latitudes 55 – 65°N



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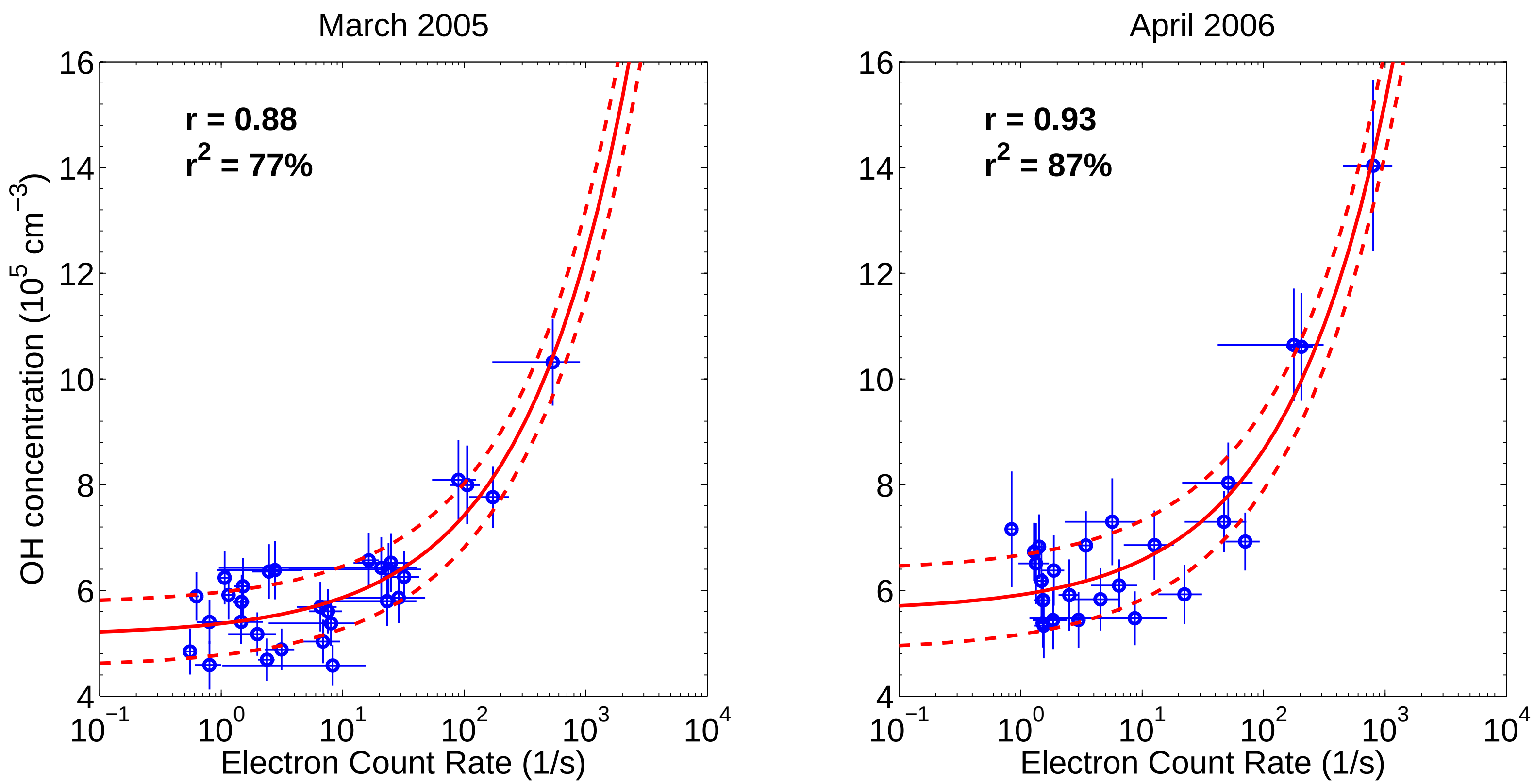
Electron count rate vs. OH concentration

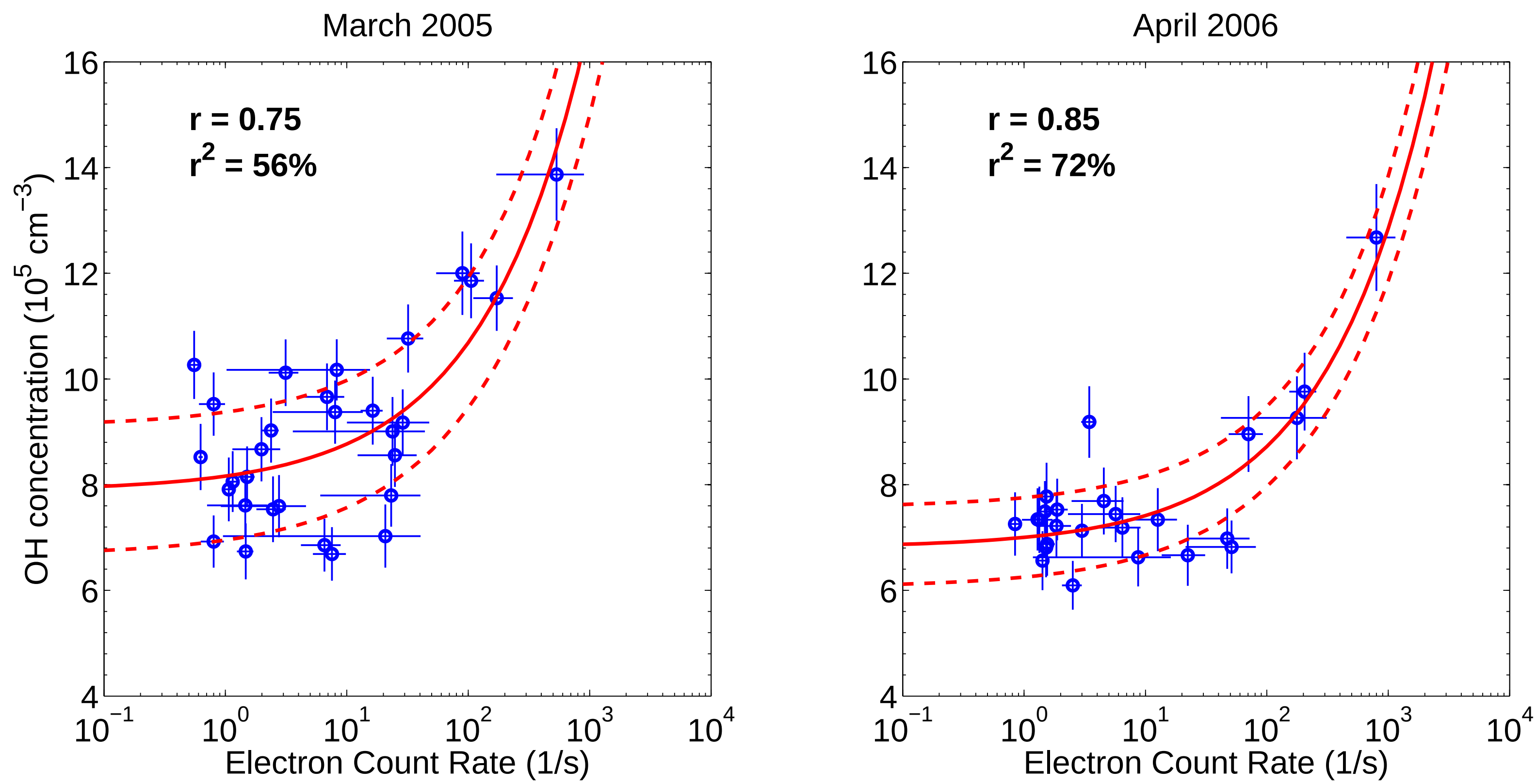
Daily averages, magnetic latitudes 55 – 65°N



High electron count rates correspond to high OH concentrations!

Electron count rate vs. OH concentration

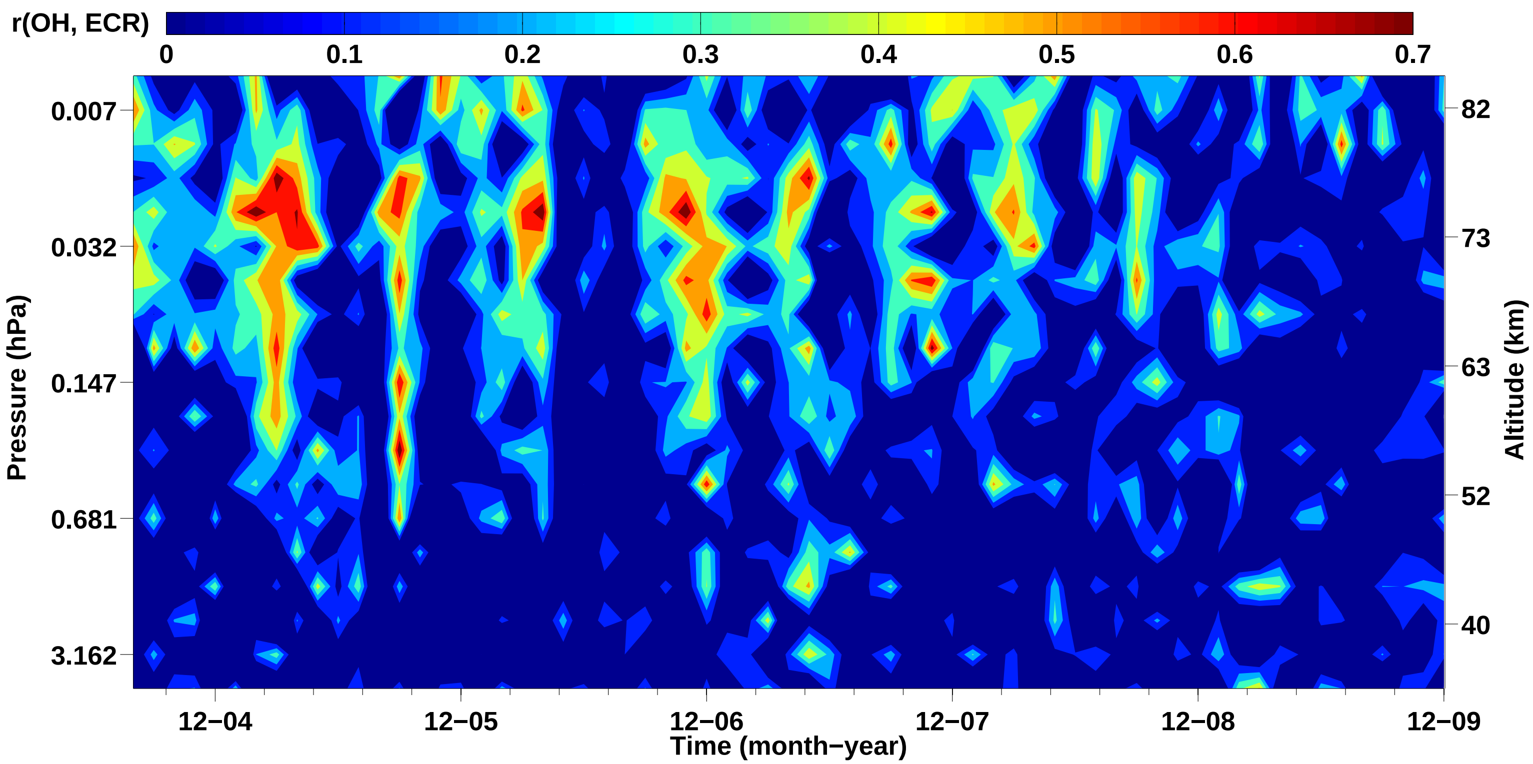
Daily averages, magnetic latitudes 55 – 65°S



Higher background OH, higher electron flux threshold

Correlation r(OH,ECR) in 2004–2009

Magnetic latitudes 55 – 65°N

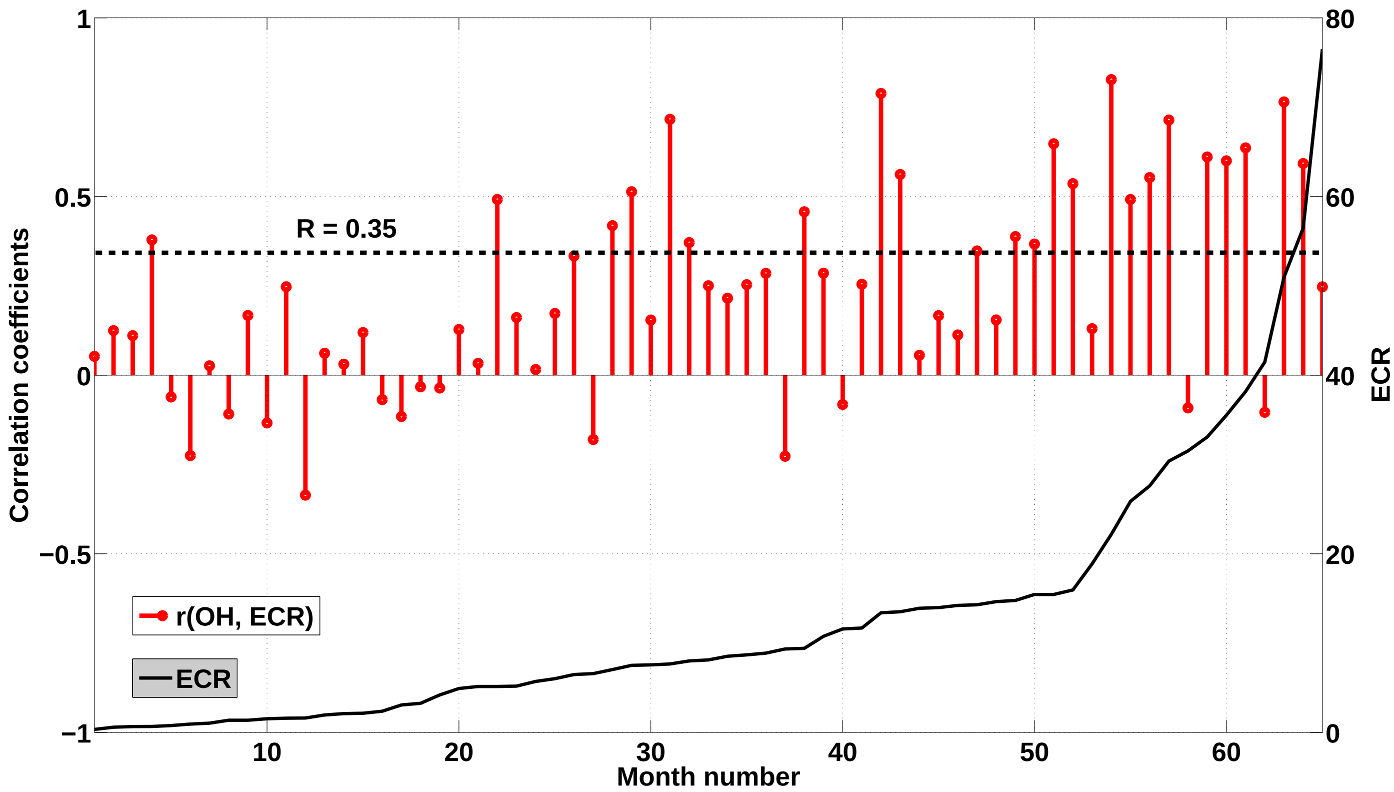


– Declining solar activity, declining correlation

– No stratospheric correlation, no effect by >3 MeV electrons

Correlation r(OH,ECR) in 2004–2009 at 75 km

Magnetic latitudes 55 – 65°N

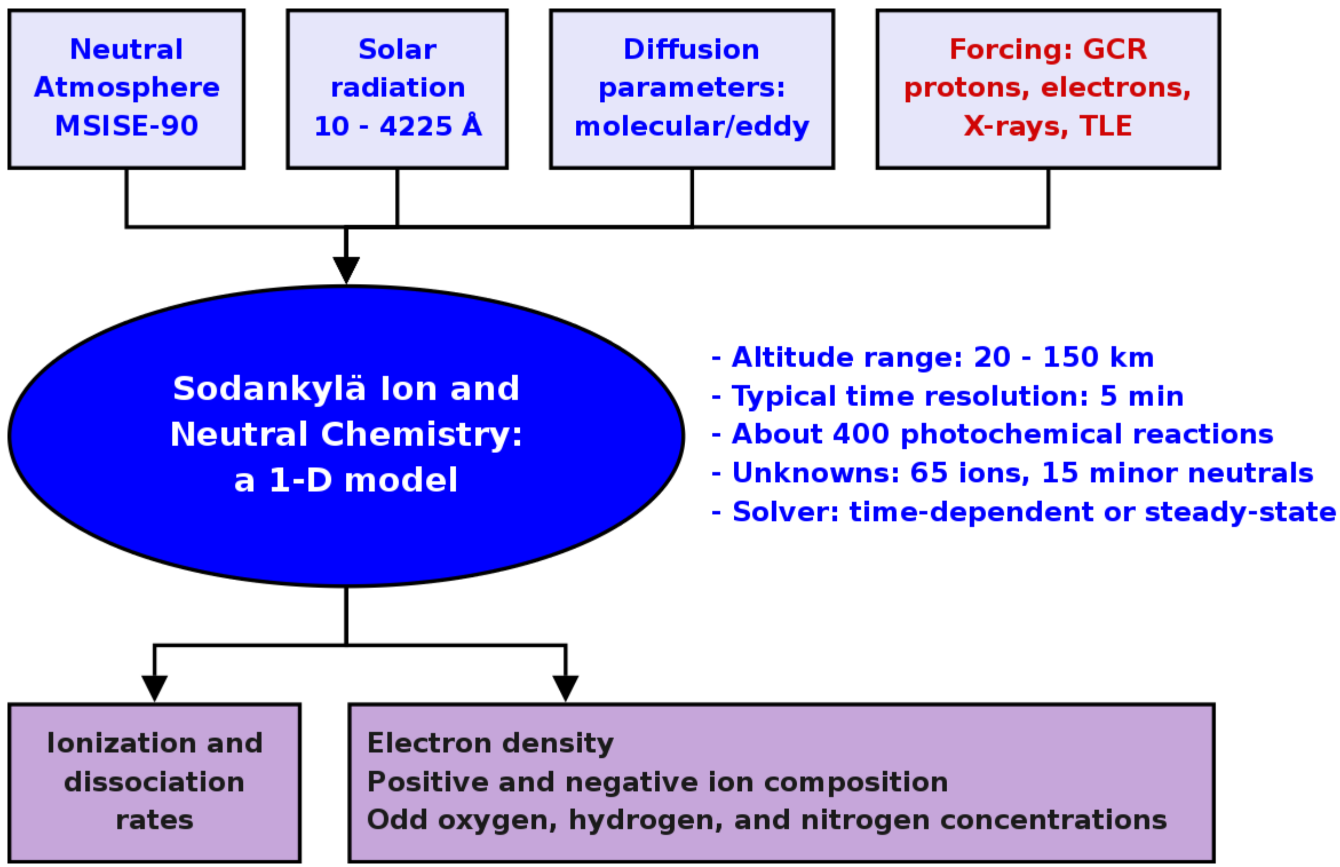


35% of months show electron impact in the mesosphere ($r > 0.35$)

Describing the energy-flux spectrum of electrons

- Electron energies 50–2000 keV are considered, affecting altitudes 90–50 km.
- MEPED measures electron fluxes at energies >30, >100, and >300 keV.
- MEPED observations are used to fit an electron energy spectrum, the power-law form of the spectrum is based on observations of the IDP/DEMETER instrument, which has a much better energy resolution than MEPED.
- Note that recent ionospheric studies have indicated that flux correction factors up to a factor of 10 may be needed for MEPED data (Hendry et al., 2012; Clilverd et al., 2012)

Sodankylä Ion and Neutral Chemistry (SIC)



SIC: example of HO$_x$ production paths

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

Modelling approach

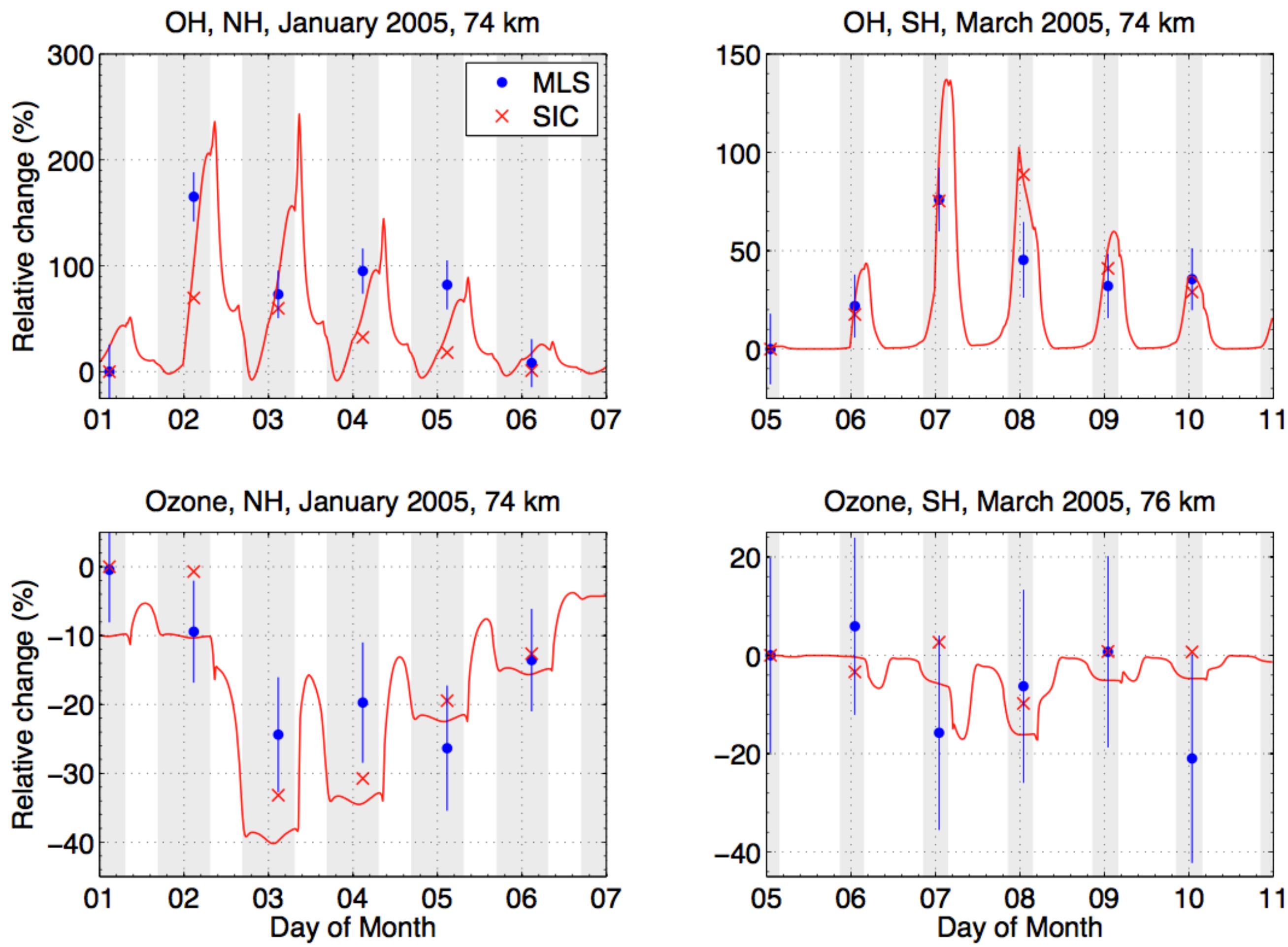
- Four months with high electron fluxes were considered:
  January 2005, March 2005, May 2005, and April 2006.
- Model input:
  daily zonal mean electron fluxes calculated using data from three MEPED instruments.
- Model locations:
  two latitude/longitude points, one in each hemisphere, at 60° of magnetic latitude.
- Model runs:
  two runs, one with daily electron forcing (EEP), one with constant quiet-time electron background (CTR).

– Using daily mean data improves the signal-to-noise ratio, and compensates differences between MEPED and MLS data sampling.

– We are not comparing fine details here, but want to know if the model can produce anything similar to the observations.

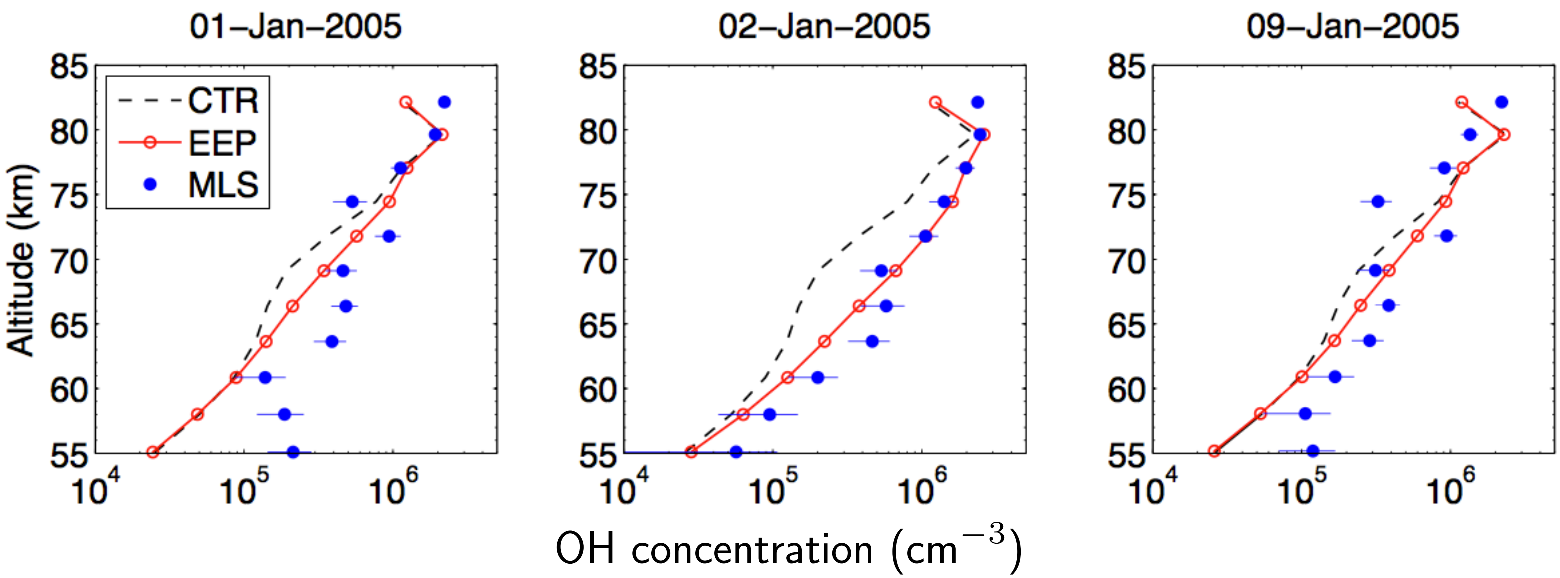
Comparison of relative OH and ozone changes

Magnetic latitudes 59 – 65°



Comparison of OH altitude profiles

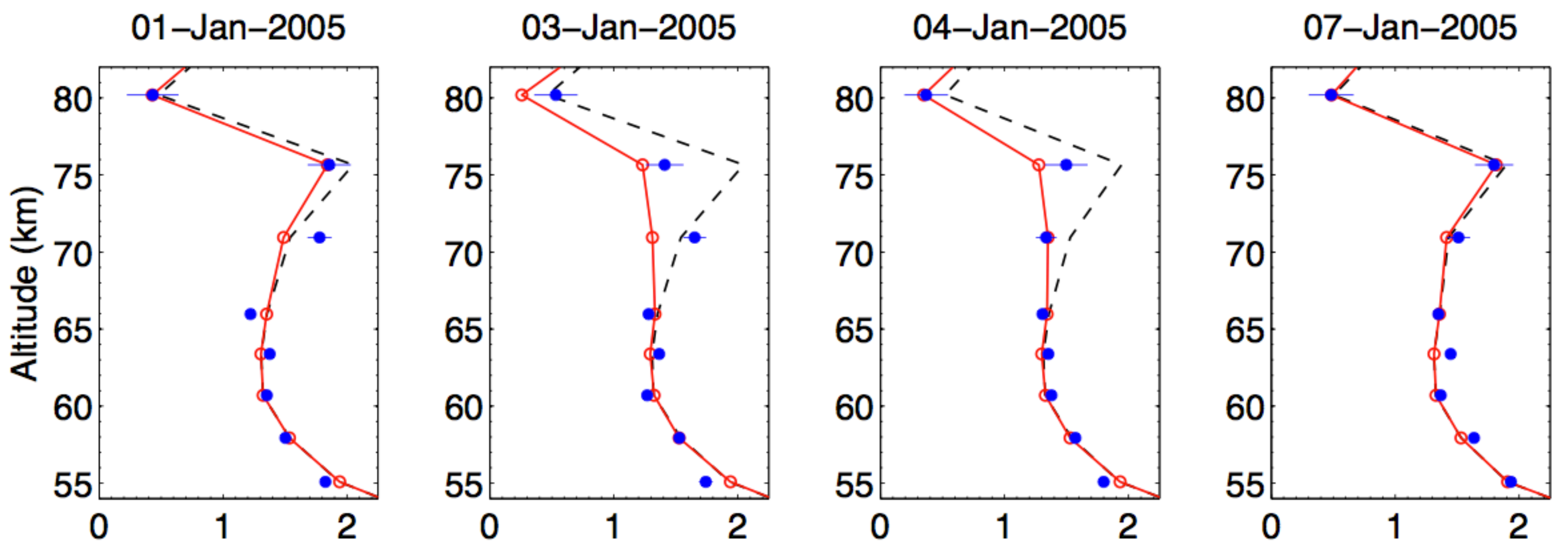
Magnetic latitudes 59 – 65°N



- OH increases between 60 and 80 km, which is in agreement with our correlation results.
- At 70–80 km (E $<$ 300 keV) there is no need for factor-of-10 flux corrections.
- SIC generally underestimates OH below 70 km, electron flux/spectrum needs adjustment?
- However, the differences are relatively small (log scale!) and there are other possible reasons.

Comparison of ozone altitude profiles

Magnetic latitudes 59 – 65°N



O_3 mixing ratio (ppmv)

- Ozone decreases above 65 km.
- SIC and MLS are in reasonable agreement.
- Again, no need for substantial flux corrections above 70 km (E $<$ 300 keV)

Summary

- Energetic electron precipitation (EEP) is significantly affecting mesospheric odd hydrogen at the magnetic latitudes connected to the outer radiation belt.
- In March 2005 and April 2006, EEP causes factor-of-two increases in daily average OH at 71–78 km altitude and can explain 56–87% of OH day-to-day variability.
- On a longer term, analysing data sets extending from 2004 to 2009 (65 months), we find that 35% of the time there is a clear correlation between EEP and mesospheric OH.
- No electron signature is found in stratospheric OH. This indicates that $>$3 MeV electron fluxes are relatively small.
- Comparisons between Sodankylä Ion and Neutral Chemistry model and MLS/Aura observations indicate that EEP-caused ozone changes can be tens of percent at 70–80 km.
- Electron flux correction may be needed at energies $>$ 300 keV, but we cannot make strong conclusions based on the MLS data at altitudes below 70 km.

More information

- Verronen, P.T., Rodger, C.J., Clilverd, M.A., and Wang, S., First evidence of mesospheric hydroxyl response to electron precipitation from the radiation belts, *J. Geophys. Res.*, *116*, D07307, http://dx.doi.org/10.1029/2010JD014965, 2011.
- Andersson, M.E., Verronen, P.T., Wang S., Rodger, C.J., Clilverd, M.A., and Carson, B.R., Precipitating radiation belt electrons and enhancements of mesospheric hydroxyl during 2004–2009, *J. Geophys. Res.*, *117*, D09304, http://dx.doi.org/10.1029/2011JD017246, 2012.
- Verronen, P.T., Andersson, M.E., Rodger, C.J., Clilverd, M.A., Wang, S. and Turunen, E., Comparison of modeled and observed effects of radiation belt electron precipitation on mesospheric hydroxyl and ozone. Submitted to *J. Geophys. Res.*, 2013.