Precipitating radiation belt electrons and enhancements of mesospheric hydroxyl during 2004 - 2009

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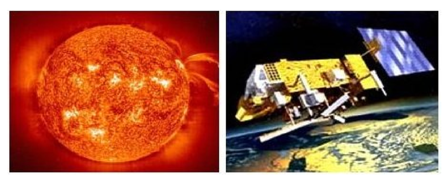


Earth Observation Unit

Introduction

In the middle atmosphere energetic electrons precipitation (EEP) is an important mechanism which affects the neutral atmosphere and results in the enhancement of HO_x through chemistry connected with ion pair production, water cluster ion formation and neutralisation.

The odd hydrogen family (HO_x= H + OH + HO_2), especially hydroxyl (OH), has significant implications to the ozone (O_3) chemistry participating in catalytic reaction cycles that destroy ozone, and in reactions between different forms of other ozone depleting compounds.

Using measurements from the Microwave Limb Sounder (MLS) onboard the Aura satellite and Medium Energy Proton and Electron Detector (MEPED) onboard POES satellite between 2004-2009, we study the effect of energetic electron precipitating from radiation belts onto nighttime OH at geomagnetic latitudes 55-65°in the Nothern and Southern hemisphere

Data & Method

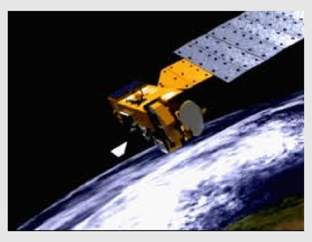
MLS (AURA)

Data:
Version 3.3 Level 2 nighttime OH, H_2O, and T

Time period:
August 2004 - December 2009

Geomagnetic latitude:
55-65° North and South

Altitude range:
50-78 km



MEPED (POES)

Data:
Electron count rates (ECR) from 0° detector pointing radially outwards along the Earth-satellite direction

Energy channels:
>300 keV - >100 keV

L shells:
3.0-5.5 - inner and mid parts of the outer radiation belt

ECR during solar proton events (SPEs) excluded from analysis

SPEs Lyman α

SPEs:
>5 and >10 MeV proton fluxes from Geostationary Operational Environmental Satellite (GOES-11)

Lyman α:
fluxes from from Lasp Interactive Solar Irradiance Data Center

Data details

SEM: standard error of the mean.
n: number of data profiles or points per day

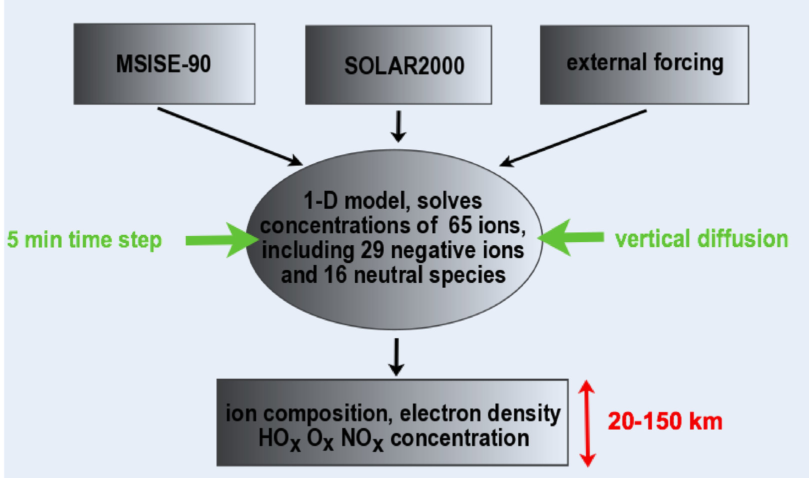
Data	SEM_{day} (%) NH/SH	SEM_{month} (%) NH/SH	n_{min} NH/SH	n_{max} NH/SH
OH	7/16	8/6	11/43	115/198
H_2O	2/4	2/1	11/40	114/195
Temperature	0.2/0.3	0.4/0.3	11/43	115/197
I_α^{SZA}	–	3/5	–	–
ECR	26	42	–	–

Method

- **Pearson's product-moment correlation** coefficients using daily mean data of ECR and OH
- **1st- and 2nd-order partial correlation** with the H_2O, T and Lyman α taken as controlled variables
- Calculations separately for each month of MLS observations between 38-85 km
- The statistical robustness of the correlation was determined by calculating the p value (t-test) and using bootstrap method

Model

Sodankyla Ion and Neutral Chemistry model



Results

MLS OH variations

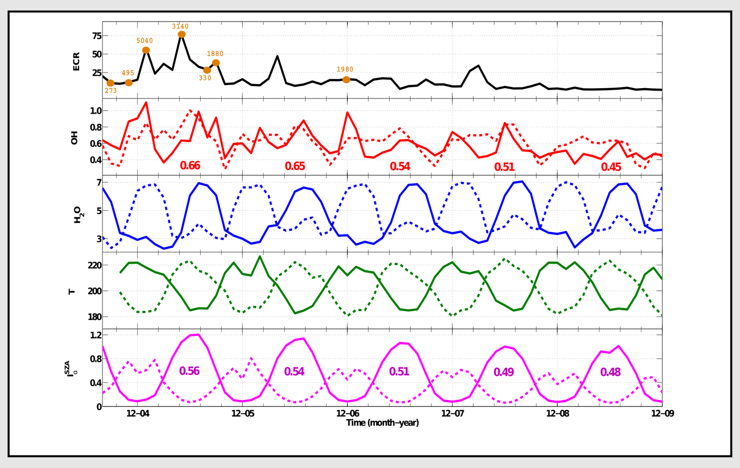


Fig 1. Zonal monthly meatn of electron count rates, OH, H_2O, T and solar radiation. SPEs are indicated by orange circles.

- H_2O, T and Lyman α: clear annual periodicity
- OH exhibits spikes, which coincide with particle forcing especially during the SPEs
- Lyman α : transition from high to low solar activity
- OH changes consistent with declining solar activity
- Decreasing trend of the electron fluxes in the radiation belts

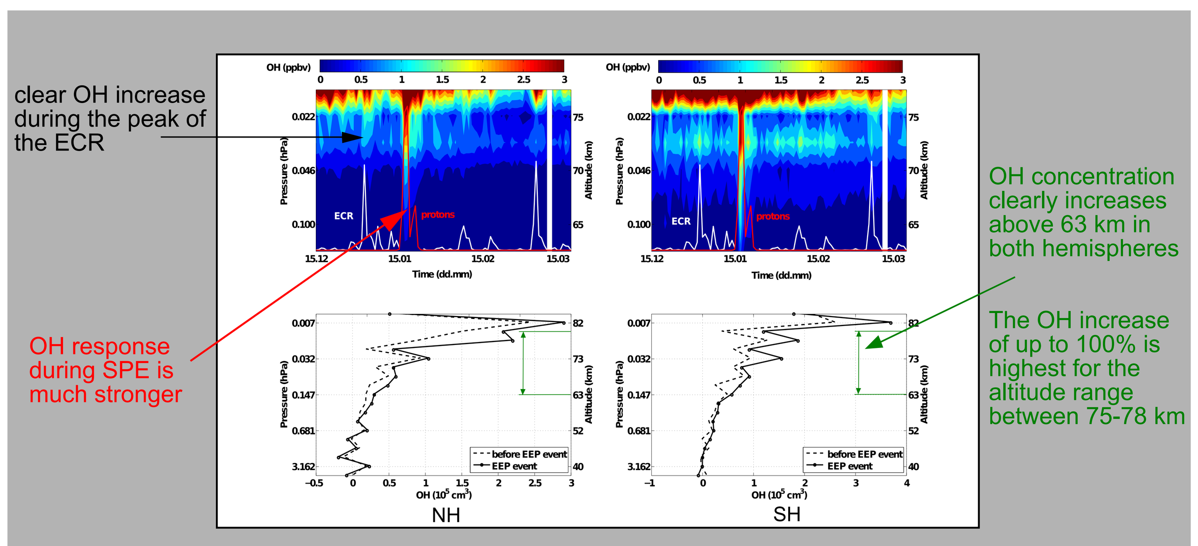


Fig 2. Top: OH mixing ratio between 15.12.2004 and 15.03.2005. Bottom: OH concentration profiles for selected days in March 2005.

Correlation analysis

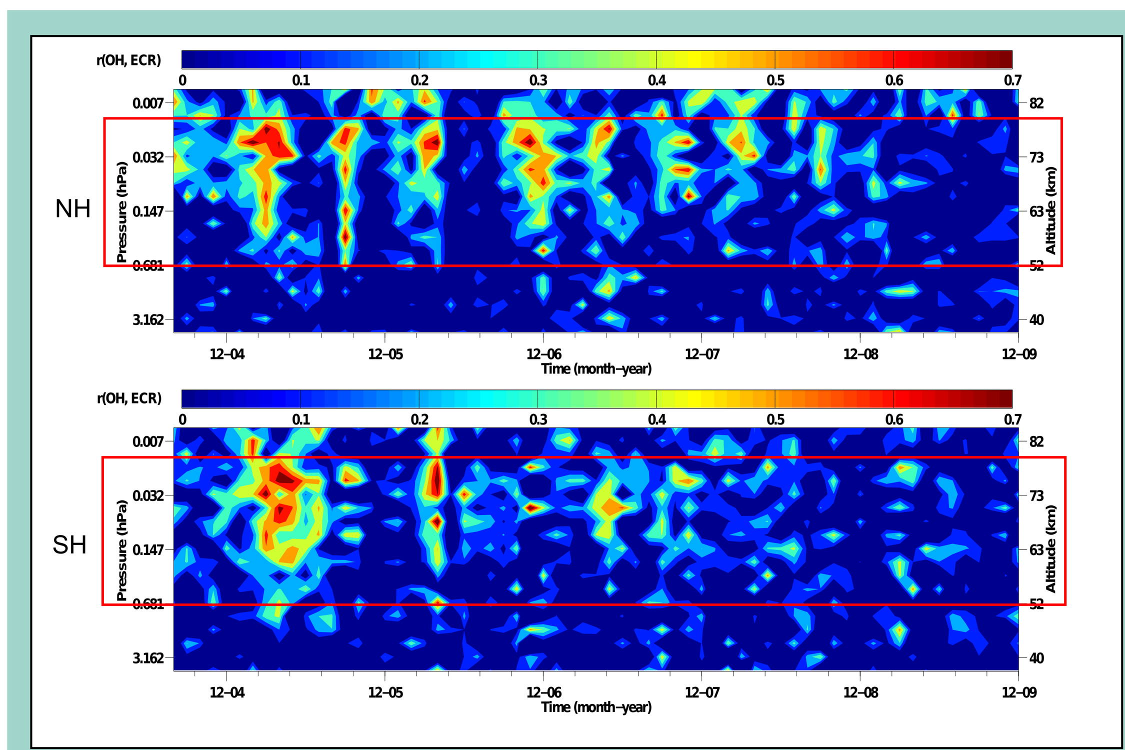


Fig 3. Correlation coefficients map between OH mixing ratio and electron count rates for 38-78 km.

- Correlations between OH and precipitating electrons is high for almost all the months with days of very high ECR
- At 75 km in the NH, for 22 months (34%) of the total of 65 analyzed, the correlation is statistically significant (r > 0.35, p<0.05)
- In the SH, for 20 months (31%) of the total of 65 analyzed, the correlation is equal or higher than 0.35
- In 10 cases in the NH and 5 in the SH r > 0.6 (p<0.01)
- Correlations r > 0.35 observed down to 52 km
- Below 52 km, for most cases, r does not exceed 0.2

- Clear increasing trend in the correlation between OH and ECR
- No clear patterns for the correlation between OH and the product of H_2O and I^{SZA}

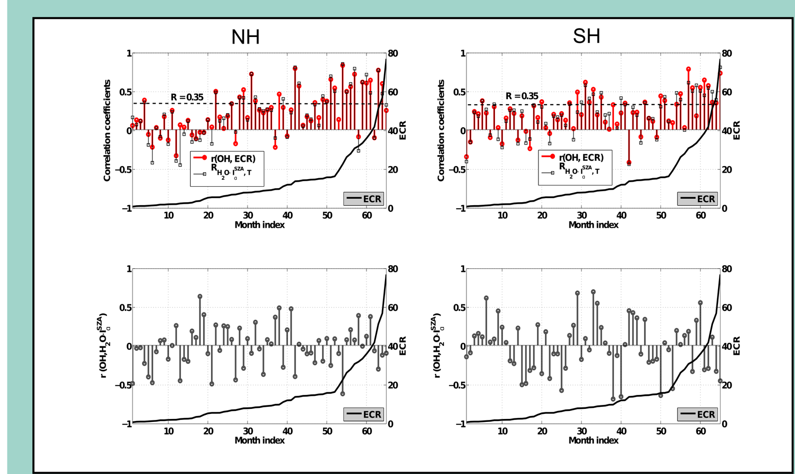


Fig 4. Top: Correlation between OH and ECR sorted in ascending order by monthly mean ECR- Bottom: as top but for OH and $H_2O \cdot I^{SZA}$

- Increasing trend in the correlation between OH and ECR for altitudes 65 and 75 km
- Below 50 km, correlation does not show an increase with increasing monthly mean ECR

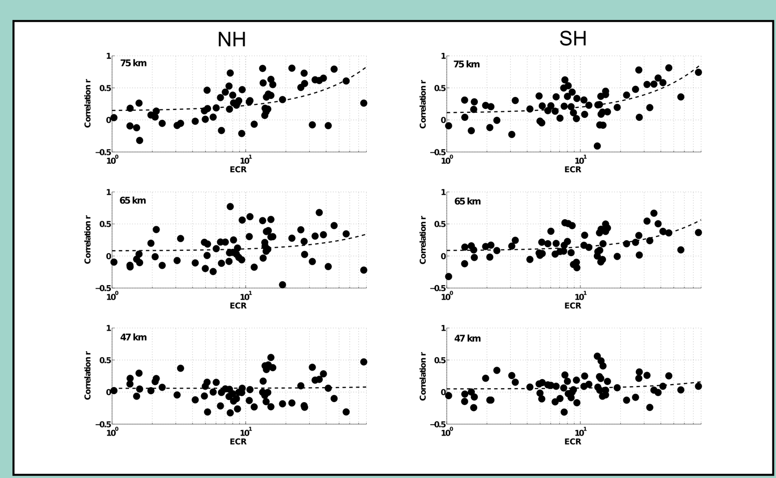


Fig 5. Correlation coeffcients between OH mixing ratios and ECR at different altitudes sorted in ascending order by monthly mean ECR

- In the NH, the strongest correlation is observed at 55-65° for all cases
- In the SH, high correlation observed also at geomagnetic latitudes 65-72°

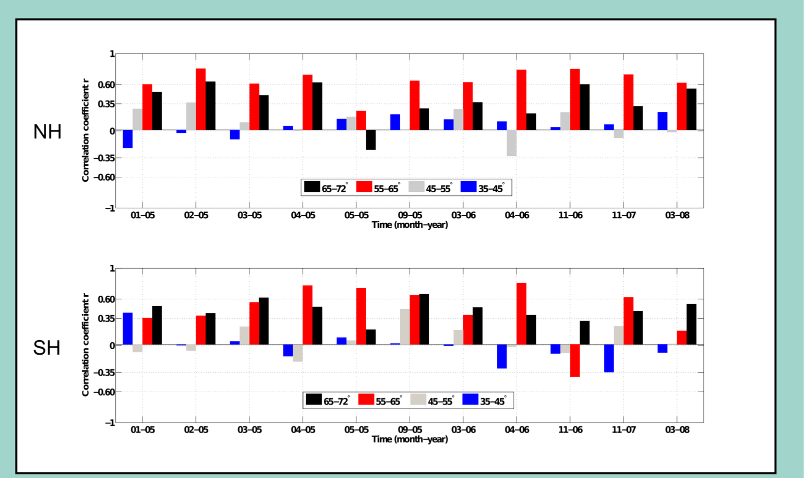


Fig 6. Correlation coeffcients between OH mixing ratio and ECR at different geomagnetic latitudes.

Partial correlation

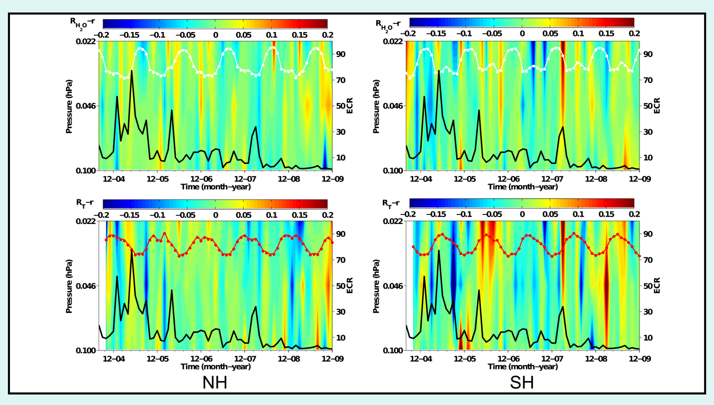


Fig 7. Differences between partial correlation coefficients and ordinary correlation coefficients r (top– R_{H_2O}, bottom– R_T).

- In average, differences between R and r are small
- Partial correlation is higher in most of the cases
- Large differences in the SH, during spring/autumn periods (March 2008)

Hemispheric asymmetry

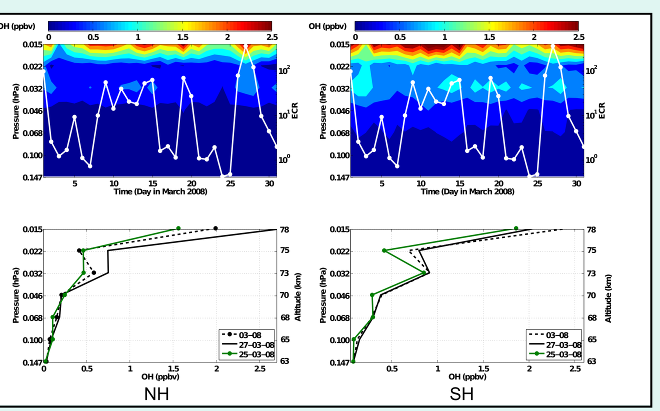


Fig 8. Top: OH mixing ratio between 63–78 km in March 2008. Bottom: OH mixing ratio profiles for selected days in March.

- OH increases due to strong electron forcing in both hemispheres
- Monthly mean OH value in the SH is higher than in the NH and close to the OH mixing ratio during ECR event
- EEP - related OH production is clearly more pronounced

OH sensitivity to H_2O and T - SIC model results

- Changing H_2O by 15% in the NH and by 50% in the SH, the nighttime OH mixing ratio changes by about 5% and 15%, respectively.
- Temperature increases by 5% in the NH and changes nighttime OH mixing ratio in average by about 5% whilst in the SH the temperature increases by 15% and changes the nighttime OH mixing ratio in average by about 20%.
- OH concentration is more sensitive to changes in temperature than those of H_2O
- For both H_2O and T, at nighttime the sensitivity is modest compared to daytime, which indicates a better possibility of identifying EEP effects at night.

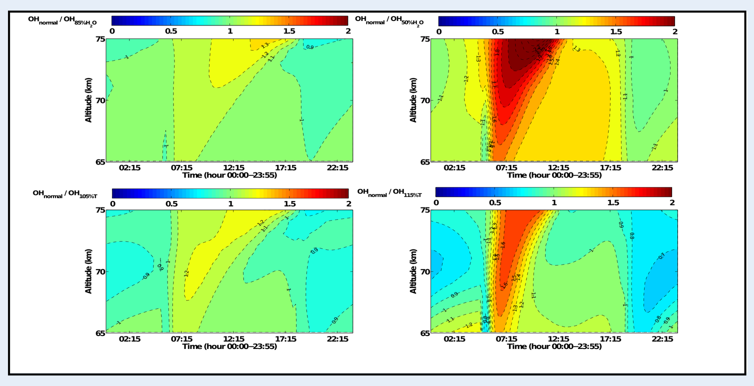


Fig 9. SIC model results - sensitivity of OH to H_2O (top) and T (bottom) in March 2008.

Conclusions

- EEP is a significant source of mesospheric HO_x at latitudes connected to the outer radiation belt
- Between 70-78 km altitudes in 22 out of 65 months (34%) in the NH and in 20 out of 65 months (31%) in the SH, the correlation is statistically significant and indicates a measurable EEP effect on OH
- At 75 km, 10/5 months in the NH/SH have correlation equal or higher than 0.6
- EEP-related OH changes are more difficult to detect in the SH, mainly due to higher OH background or stronger water vapor and temperature influence
- No evident correlation between ECR and OH below 52 km, >3 MeV electrons do not have a detectable impact on OH in the stratosphere
- Correlation at lower geomagnetic latitudes bands, i.e., 35-45° and 45-55° are in general lower than than this for higher latitudes
- Considering that the time period 2004-2009 analysed here coincided with an extended minimum of solar activity, our results provide a lower-limit estimation of the importance of EEP on HO_x

References

- Andersson, M. E., et al. (2012) Precipitating radiation belt electrons and enhancements of mesospheric hydroxyl during 2004-2009, J. Geophys. Res. 117
- Verronen, P. T., et al. (2011) Evidence of mesospheric hydroxyl response to electron precipitation from the radiation belts, J. Geophys. Res. 116
- Minschwaner, et al. (2011) Hydroxyl in the stratosphere and mesosphere - Part 1: Diurnal variability, Atmos. Chem. Phys., 10
- Rodger, C. J., et al. (2010) Use of POES SEM-2 observations to examine radiation belt dynamics and energetic electron precipitation into the atmosphere, J. Geophys. Res., 115

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