Effect of high energetic particles on Nitric Oxide measured by Odin-SMR and AIM-SOFIE

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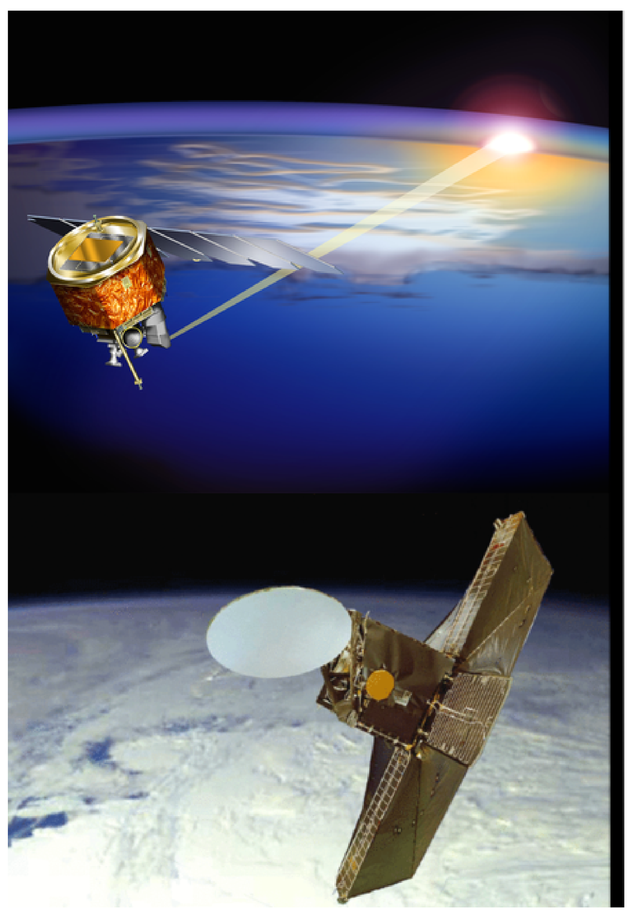
Abstract:

High energetic particles originating from our Sun affect the Earth's atmosphere by for example increasing the amount of reactive nitrogen NOx. Through catalytic reactions this reactive nitrogen can lead to an increased ozone break down and temperature gradients, which implies altered atmospheric dynamics.

The Sub-Millimeter Radiometer (SMR) onboard of the Odin satellite measures trace gases in the strato-, meso- and lower thermosphere via limb scanning.
Odin is a polar sun-synchronous satellite, operational since 2003, with 14 orbits a day and 35 scans per orbit.
Since 2007 Odin measures NO for 3 observational days in a two week cycle in the altitude range of 20-120km. Via detection of thermal emission lines SMR is able to determine the NO concentrations. This technique allows measurements during the polar night.
Odin passes the same latitude band every 96 minutes, so it proves to be difficult to judge whether the evolution of mesospheric NO concentrations is due to temporal or spatial changes or a combination of both.



Upper left: AIM satellite with SOFIE instrument
Lower left: ODIN satellite with SMR instrument
Right: Satellite tracks around Earth (14 orbits/day)

The Solar Occultation For Ice Experiment (SOFIE) onboard of the AIM satellite measures similar trace gases as SMR but via the amount of solar energy passing through the atmosphere at sunrise and sunset, which limits the latitudinal coverage of AIM from 65° to 85° North and South.
NO is retrieved daily since 2007 in the 10-150km altitude region, so we have 7 years of coincident measurements between Odin and AIM.
Combining NO data from SMR and SOFIE results in a better spatial and temporal coverage of Earth.

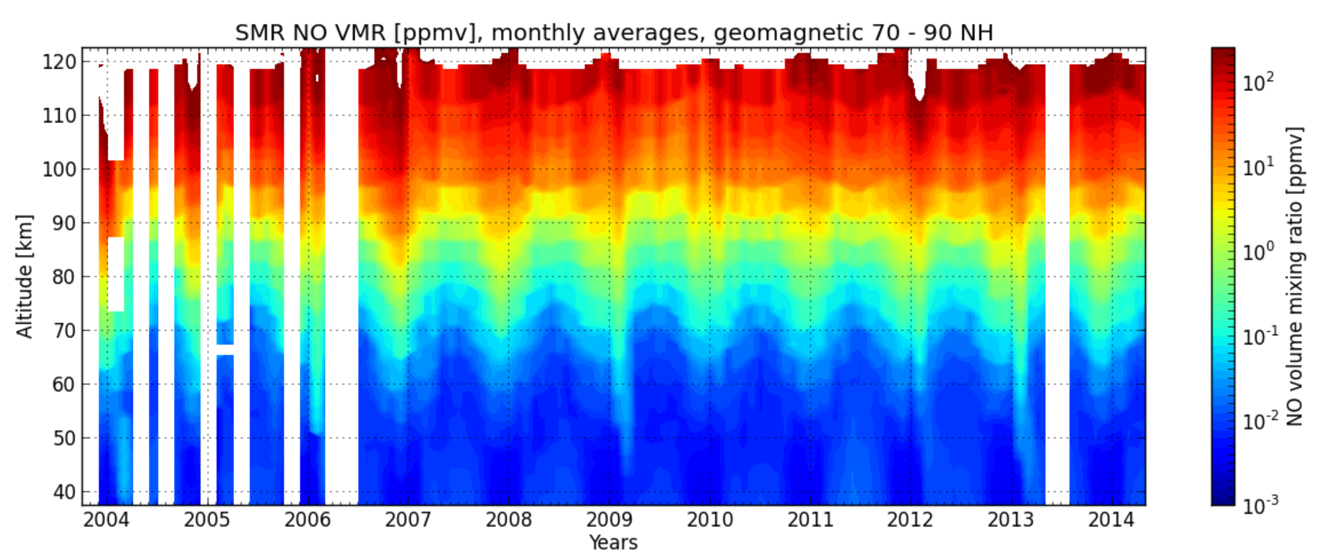


Figure 1: Temporal evolution of Northern Hemispheric NO monthly averages, measured by SMR.

Figure 1 shows a temporal evolution of monthly NO averages in the Northern Hemisphere, taken by SMR. From 2003 to 2007 SMR measured NO approximately only once a month, but since 2007 measurements increased to 6 or 7 on a monthly basis.
Large NO densities are present in the lower thermosphere (100-120km) and decrease gradually towards meso- and stratosphere.
Nitric Oxide is produced by energetic electrons precipitating into the atmosphere and gets destroyed by sunlight. This results in a yearly cycle of NO build up during the dark polar winter. Sudden Stratospheric Warming events occur on an irregular basis around January/February and allow NO to be transported downwards into the stratosphere: this happened in the winters of 2003-2004, 2005-2006, 2008-2009, 2012-2013 and can be seen as a green 'tongue' in the figure.

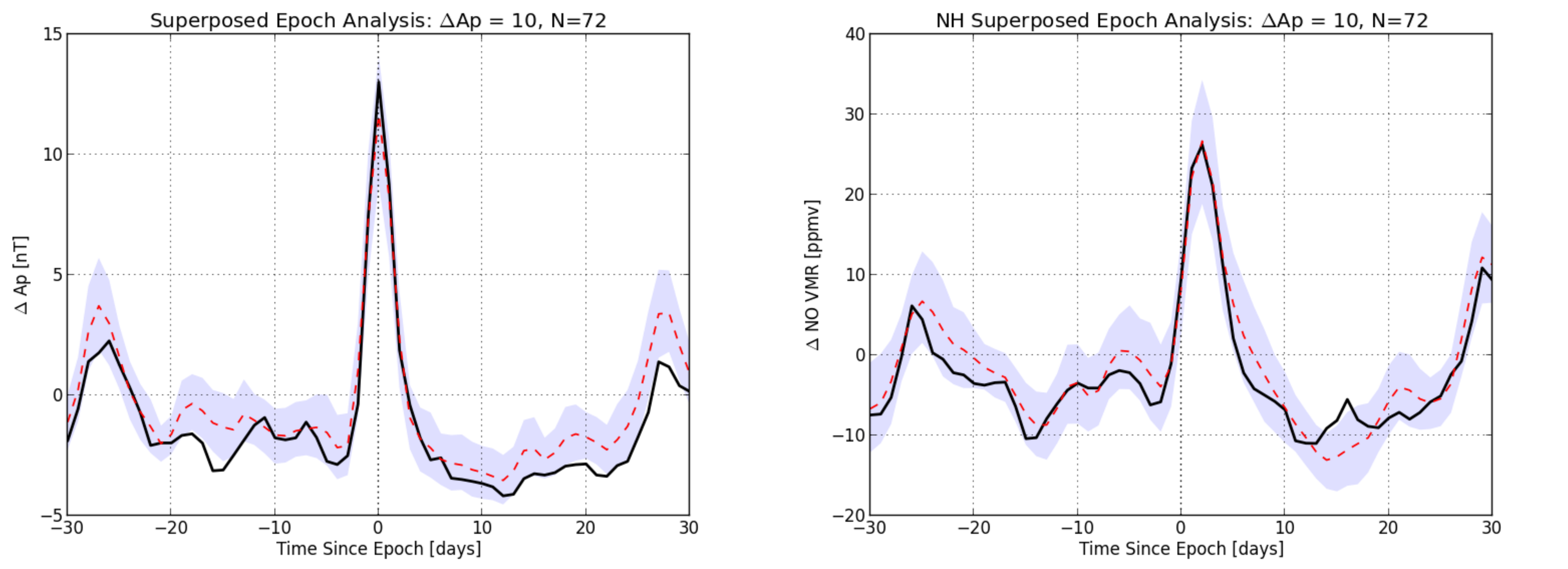


Figure 2: Superposed Epoch Analysis of variations in the geomagnetic A_p index and Northern Hemisphere NO (from SOFIE), showing the 27-day solar cycle and a 1-2 day delay in NO response.

The geomagnetic planetary A_p index is an indicator for geomagnetic storms, caused by the arrival of Coronal Mass Ejections (CME) or Corotating Interaction Regions (CIR) originating from the Sun, and is an indication for the flux of precipitating particles.
Figure 2 shows a Superposed Epoch Analysis, also known as composited analysis, for the variation in A_p and NO. Increases in A_p follow the 27-day cycle of solar rotation, as does the variation in NO but with a delay of 1 to 2 days. This is an indication that NO and A_p will have a maximum correlation with a 1 or 2 day lag.

Figure 3 shows the correlation between NO and A_p in function of altitude in winter and summer time and for the Northern and Southern Hemisphere. Linear correlation coefficients are calculated for 90 days of SOFIE NO and A_p, centered around the solstices in June and December. Only correlations that were significant at the 95% significance level are shown.

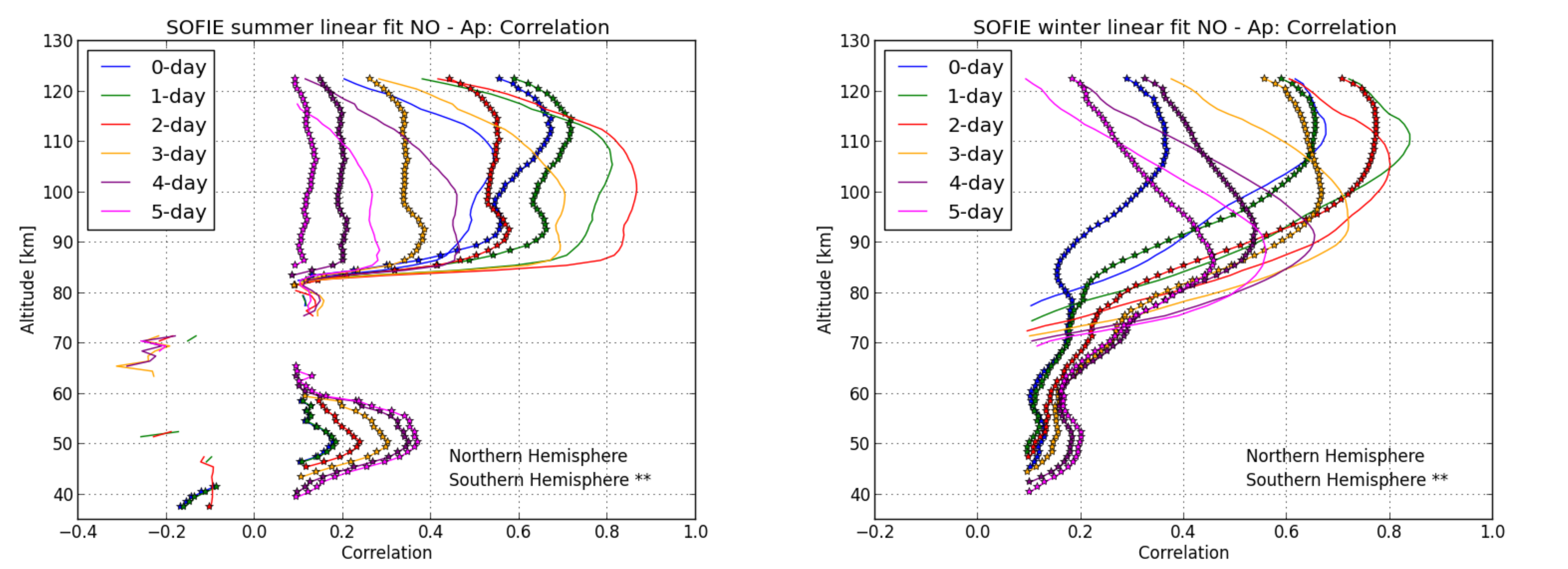


Figure 3: Altitude dependence of the correlation between NO and A_p in both hemispheres, during summer time (left) and winter time (right).

In summer time NO gets broken down by sunlight so a nearly constant correlation is found in the lower thermosphere, with highest correlations found for 1 or 2 days lag in A_p. A smaller correlation further down is found as well: this may be due to relativistic electrons which are able to penetrate deeper into the atmosphere.
In winter time NO has a lifetime of about a month and concentrations are able to build up. Both hemispheres show a maximum correlation with A_p at around 110km which decreases in altitude as the lag becomes larger. This suggests a downward transport of NO, most likely due to molecular and eddy diffusion.
We also noticed a difference in the slope of the performed linear fit between winter and summer time conditions. The change in NO per A_p change (not shown here) is higher in winter than in summer which indicates that in summer time less NO will be produced per A_p change due to NO breakdown by sunlight.

Conclusion and outlook:

We have confirmed the existence of a linear relationship between Nitric Oxide and the geomagnetic planetary A_p index. This correlation is most pronounced at an altitude of approximately 110km and is maximal with a 1 or 2 day lag in A_p. During polar winter NO gets transported down to lower altitudes due to diffusion processes.
Further we found a distinct difference in the steepness of the linear correlation between summer and winter conditions: the change in NO per A_p change is much higher in winter than in summer, indicating a seasonal behaviour.

Correlation studies between NO and other parameter such as solar wind speed, interplanetary magnetic field strength, Dst-index and electrons of different energies (measured by POES satellite) are in progress for SMR and SOFIE data. This will enable us a better understanding of the physical behaviour of NO as well as an inter-satellite comparison and validation.

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