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Observed effects of solar proton events and sudden stratospheric warmings on odd nitrogen and ozone in the polar middle atmosphere

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Introduction

We use satellite observations from ACE-FTS, MLS/Aura and SABER/TIMED to study the effects of solar proton events (SPEs) and strong sudden stratospheric warnings (SSWs) on the middle atmospheric odd nitrogen (NO_x) and ozone levels in the Northern Hemispheric polar region. Three winters (January–March) are considered:

1) 2005 with a SPE
2) 2009 with a SSW
3) 2012 with both SPEs and a SSW

These different cases provide a good opportunity to study the roles that transport from the mesospere-lower thermosphere region and in situ production due to particle precipitation have on stratospheric odd nitrogen (NO_x) and the consequent effects on the middle atmospheric ozone.

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Data

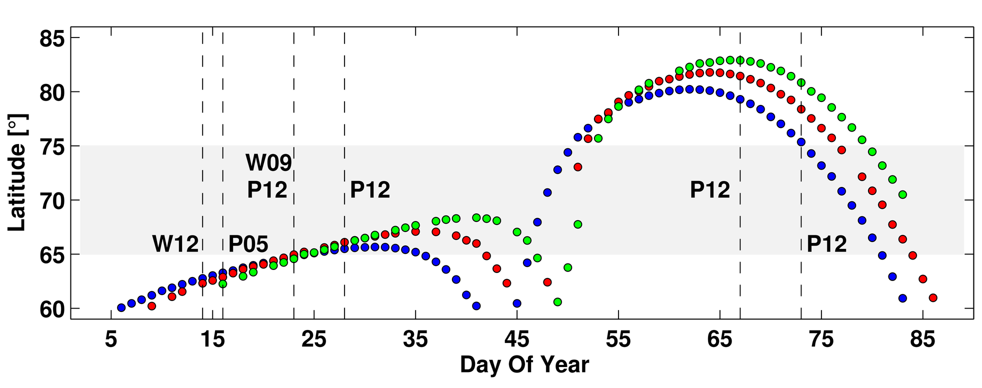

Figure 1. *Daily averages of ACE-FTS measurement latitudes in January–March 2005 (blue), 2009 (red), and 2012 (green). The latitude range (65°N–75°N) used in the analysis of SABER and MLS measurements is marked in the figure with gray shading. The vertical dashed lines show the time points for SPEs (P) and SSWs (W) during 2005 (05), 2009 (09), and 2012 (12).*

Dynamics

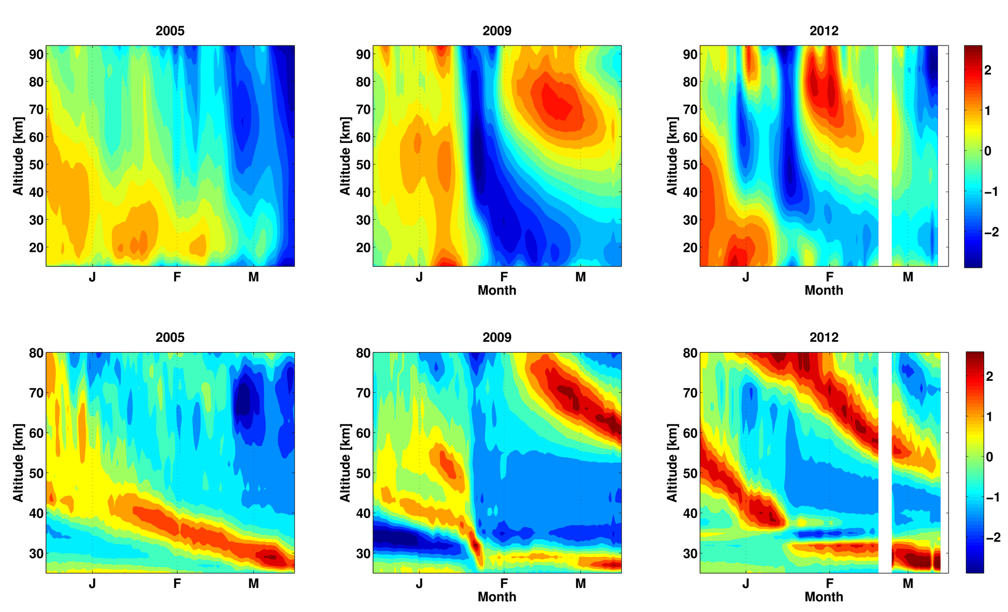

Figure 2. *NAM (top) and CNAM (bottom) indices for 2005, 2009, and 2012.*

In 2005 the vortex persisted the whole winter while in 2009 and 2012 SSWs interrupted the vortex development in late-January and mid-January, respectively. The CNAM indices agree well with the NAM indices giving descent rates of 380 m/d (2005), 570 m/d (2009), and 520 m/d (2012).

Odd Nitrogen (NO_x)

The changes for both NO_x and O_3 are calculated relative to the January–March mean 2007–2008 (no SPEs or SSWs) and poleward of 60°.

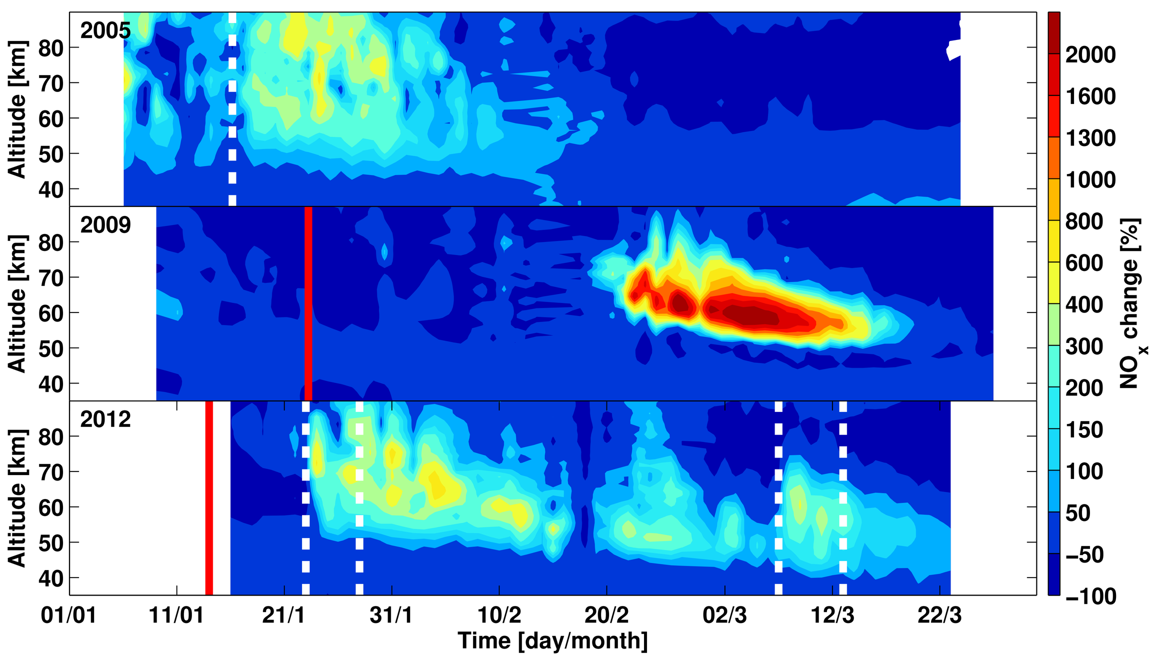

Figure 3. *Change in NO_x (%) based on ACE-FTS data in 2005 (top), 2009 (middle), and 2012 (bottom). The white dashed lines indicate the time points of the observed SPEs and the red solid lines the observed SSWs during these years.*

Year	km	%
2005	45–80	30–300
2009	50–80	100–2400
2012 (I)	50–85	100–800
2012 (II)	50–90	50–400
2012 (III)	40–75	50–400
2012 (IV)	40–45	50–100

Table 2. *Changes (%) in NO_x after SPEs and SSWs in 2005, 2009, and 2012. The four cases for 2012 indicate the different SPEs that took place in January (I and II) and March (III and IV).*

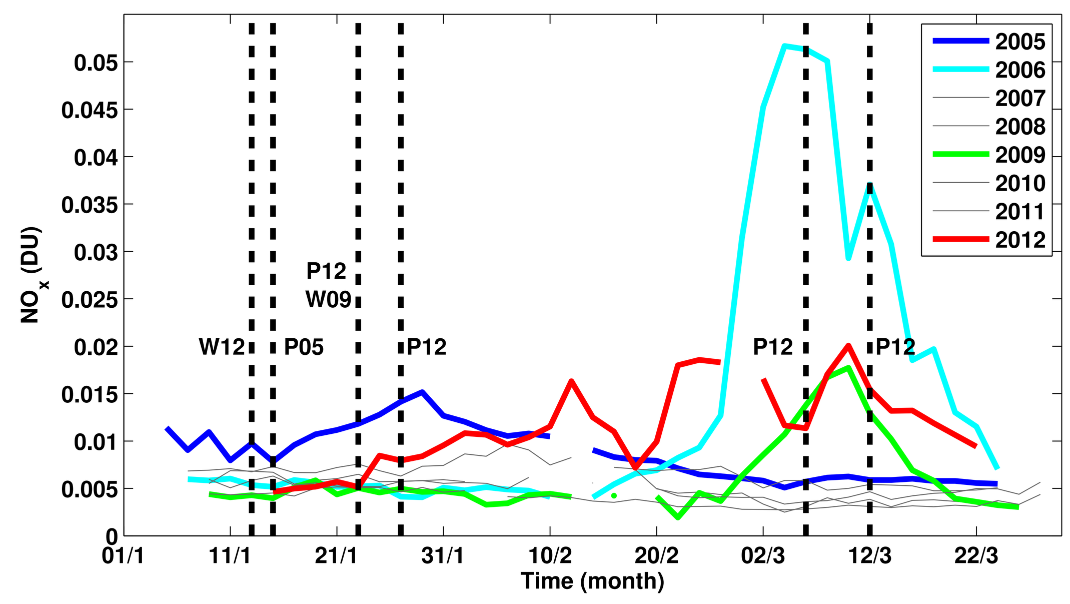

Figure 4. *Two day mean NO_x column (DU) for 46–56 km calculated from the ACE-FTS observations for the polar cap region (60°–90°).*

The amount of NO_x in the middle atmosphere in March is higher (>0.005 DU) during years with SSW events (2006, 2009, and 2012) than in dynamically nonactive years.

Ozone (O_3)

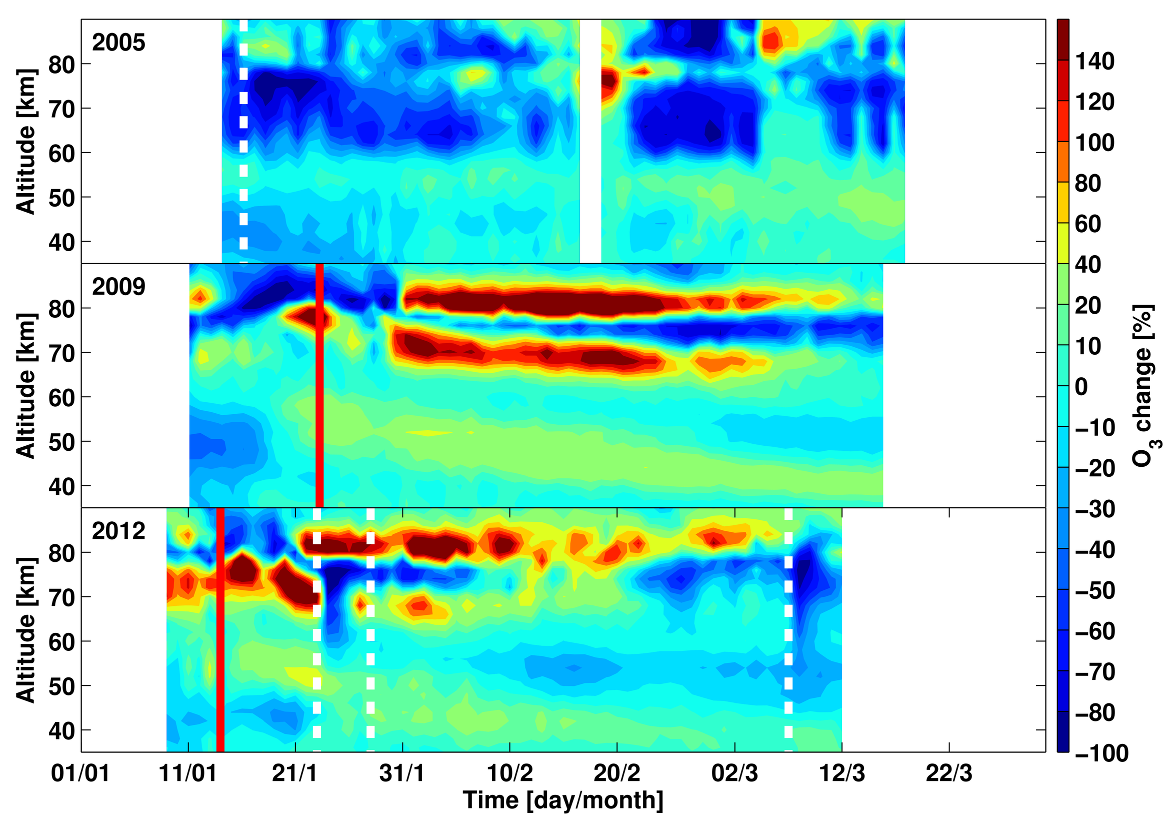

Figure 5. *Change in ozone calculated the same way as for NO_x, but using SABER observations.*

	ACE-FTS % (km)	MLS % (km)	SABER % (km)
2005	20–70 (45–80)	20–70 (50–80)	20–90 (55–80)
2012 (I)	10–80 (55–75)	10–70 (55–80)	10–90 (50–80)
2012 (II)	10–60 (55–75)	10–70 (63–80)	20–70 (70–80)
2012 (III)	10–70 (40–90)	10–70 (45–80)	20–90 (45–85)
2012 (IV)	20–30 (40–70)		

Table 2. *Changes (%) in ozone after SPEs in January 2005 and in early 2012.*

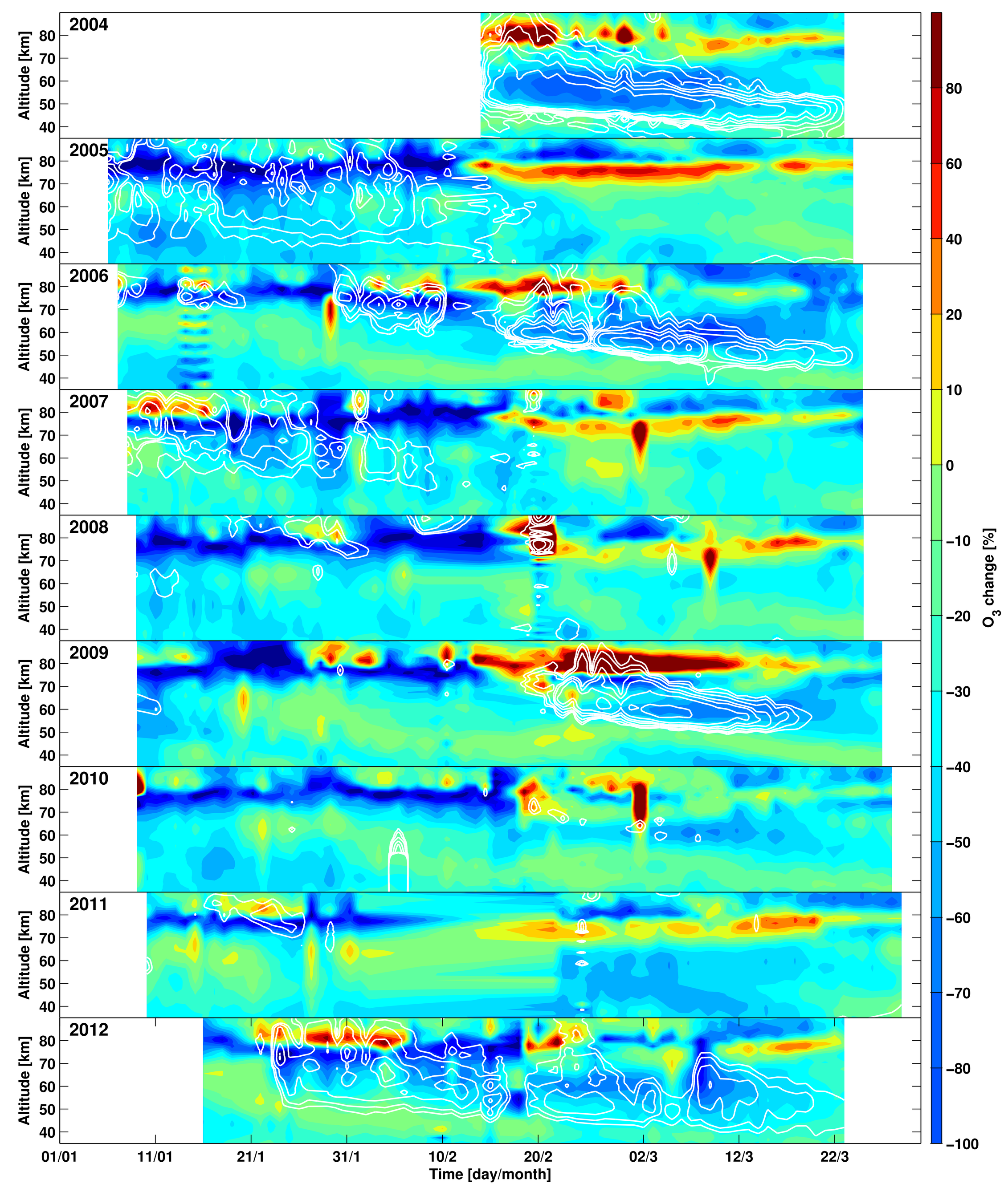

Figure 6. *ACE-FTS observations of the change (%) in ozone in 2004–2012. The overlaid contours are values of positive NO_x changes (%) (50, 100, 200, 400, 600, 1000, and 2000%).*

During years with enhanced NO_x in the middle atmosphere also decreases in ozone are observed. The factors contributing to the observed ozone losses are the HO_x cycles (short-term) in the mesosphere, NO_x cycles cycles closer to the stratopause (longer-term), and changes in the dynamics following the SSWs (longer-term).

Conclusions

- the amount of NO_x increased both after SPEs and SSWs by a factor of 1–25 at 40–90 km depending on the year and event
- ozone losses (short and longer-term) of the order of 10–90 % at 40–90 km were also observed
- largest effect in the stratosphere were observed in 2012 when both SPEs and a SSW took place
- the in situ production of NO_x was not sufficient enough to have a clearly NO_x dominated effect on the middle atmospheric ozone
- it is likely that NO_x-ozone connection is more pronounced during and after solar maximum periods than solar minimum periods (the 2009 and 2012 events)

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