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High Energy Particle Precipitation in the Atmosphere

Atmospheric impact of SEP events during the last years of solar cycle n. 23 highlighted by MLS OH radicals

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The descending phase of solar cycle n. 23 has been characterized by several Solar Energetic Particle (SEP) events. These events were not so strong as the previous ones that occurred close to solar maximum, even though they were able to impress their trails on the terrestrial atmosphere. Moreover, since August 2004 the availability of the data from Microwave Limb Sounder aboard the quasi polar orbit EOS AURA spacecraft allowed to monitor the polar middle atmosphere. In particular, the last release (MLS Version 2.2) of OH radical abundance (which extended toward the mesopause the upper boundary for the data use) confirmed that it is a very good proxy to follow transient solar activity as predicted from past modelled findings. Due to some isolated SEP events with flux around few hundreds of pfu (Particle Flux Units;1 pfu = 1 p cm^{-2} sr^{-1} s^{-1}), it was possible to test the lowest particle flux which is able to influence the middle atmosphere. In this way, the presence/absence of SEP-induced effects in the atmospheric environment seems easily to be checked very quickly.

It has been known since early ’70 that the impact of SEP events induces an increase of HO_x ($H+OH+HO_2$) on the polar atmosphere (e.g., Swider and Keneshea, 1973); nevertheless we had the possibility to compare models with experimental data only since August 2004 when the Microwave Limb Sounder (MLS) started recording OH and HO_2 radicals (Verronen et al., 2006). Since the instrument is able to make measurements also in the nighttime, when the hydroxyl abundance is low, we have the possibility to study also SEP events of medium/low intensity. Indeed, these events induce low ionization compared with other daytime sources, so the SEP-induced OH increases are often not evident under sunshine. We can utilize the MLS OH recorded at nighttime as proxy of almost all the SEP events which reach the Earth’s environment. Therefore we have a tool that can discriminate quickly whether medium SEP events are able to induce mesospheric perturbations. In this work we used OH values of daily zonal means averaged over 75°-82° latitude N&S under nighttime conditions unless otherwise noted.

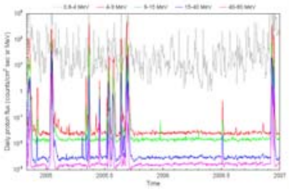

Fig. 1 – Goes daily proton flux from November 2004 to December 2006.

Particles events (pfu unit)				
Start (Day/UT)	**Maximum** (Day/UT)	**Proton flux** @>10 MeV (5 minutes)	**Proton flux** @>10 MeV (hourly)	**Fluence** @>10 MeV part./(cm² sr)
Nov 01/0655	Nov 01/0805	63	54	1.09E+06
Nov 07/1910	Nov 08/0115	495	442	1.85E+07
Jan 16/0210	Jan 16/1840	365	332	1.95E+07
Jan 17/1240	Jan 17/1750	5040	4130	2.02E+08
Jan 20/0650	Jan 20/0810	1860	1420	6.19E+07
May 14/0525	May 15/0240	3140	1900	2.87E+07
Jun 16/2200	Jun 17/0500	44	41	1.82E+06
Jul 14/0245	Jul 15/0345	134	129	1.08E+07
Jul 27/2300	Jul 29/1715	41	38	9.40E+06
Aug 22/2040	Aug 23/1045	330	311	2.28E+07
Sep 08/0215	Sep 11/0425	1880	1880	1.65E+08
Dec 06/1555	Dec 07/1930	1980	1940	1.63E+08
Dec 13/0310	Dec 13/0925	698	661	3.68E+07

Tab. 1 – SEP events list from November 2004 to December 2006.

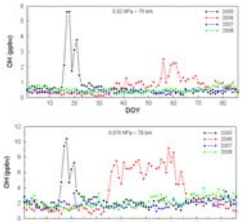

Fig. 2 – Trend of daily OH at about 75 and 78 km for 75˚-82˚ N.

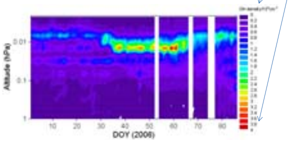

Fig. 3b – As second panel with OH in density.

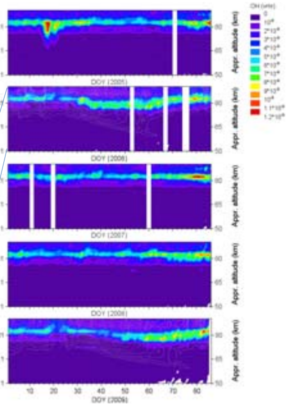

Fig. 3a – Zonal means of OH for (from upper to lower panel) 2005-2009. White dotted line: CO (vmr).

Fig. 1 shows the solar protons flux at different channels recorded by Goes from November 2004 to December 2006 when the main SEP events of the descending phase of the solar cycle occurred. The maximum flux at energy greater than 10 MeV and the fluence values are shown in Tab. 1. The main OH source in stratosphere is due to the reaction of water vapor with metastable oxygen atom, whereas in mesosphere it is due to the direct photolysis of H_2O. Cannibalistic reactions, e.g. between OH and HO_2, are the main sinks. The major OH variability is connected to diurnal cycle, with maximum OH abundance roughly at noon (Li et al., 2005); annual and semiannual oscillations are of minor importance (Canty and Minschwaner, 2002). The key feature of the OH profile recorded at nighttime is the presence of an enhanced OH layer sited at around 82 km. It is caused by the reaction of ozone with atomic hydrogen. This layer is almost constant at all latitudes (Pickett et al., 2006) and it is important because it increases the OH background near the upper boundary of the region involved by SEPs. This factor makes small changes of OH abundance, induced by minor SEP events which impact similar altitudes, not easy to point out. The intensity of the polar vortex induces additional variability to this region (see Fig. 2). Indeed, under periods characterized by strong air descent, this layer can move to lower altitudes probably because of increased transport of Ox (see Winick et al., 2009) from the thermosphere to the mesosphere (in Fig 3 the phenomenon is evident after the SSWs of January 2006 and 2009).

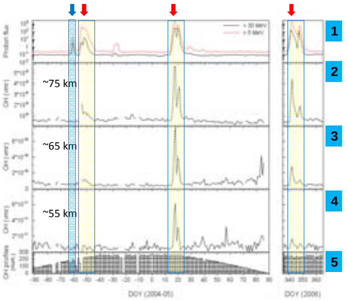

Fig. 4 – Trend (Oct. 2004-Mar. 2005) of proton flux (1), daily OH at 75 km (2), 65 km (3) and 55 km (4), number of MLS profiles used for the zonal means (5). Northern hemisphere.

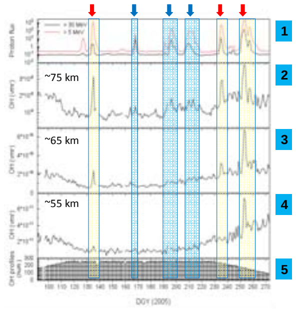

Fig. 5 – Trend (Apr. 2005-Sep. 2005) of proton flux (1), daily OH at 75 km (2), 65 km (3) and 55 km (4), number of MLS profiles used for the zonal means (5). Southern hemisphere.

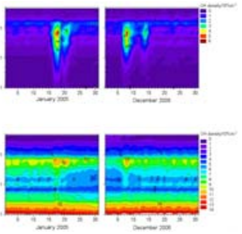

Fig. 6 – Daily zonal means of OH for January 2005 (left) and December 2006 (right) on day (top) and night (bottom).

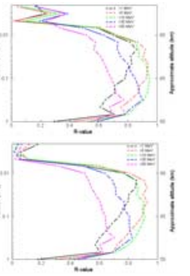

Fig. 8 – r-values of proton flux vs OH for diverse altitudes and energies (see text for details).

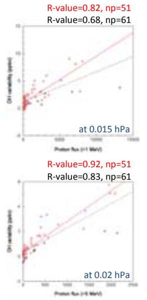

Fig. 9 – Example of regression, as Fig. 8, for energy >1 MeV (up) and >5 MeV (bottom).

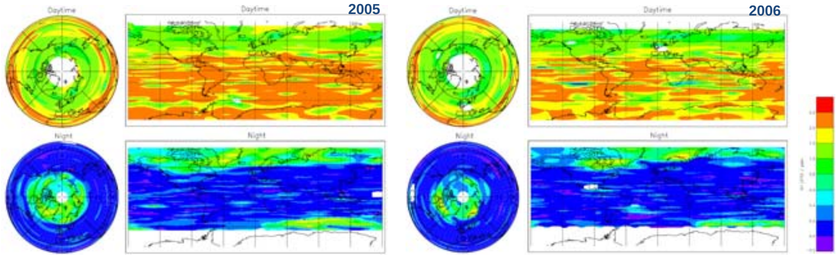

Fig. 7a – OH spatial distribution on January 18, 2005 (left side) and December 8, 2006 (right side) in polar and cylindrical projection.

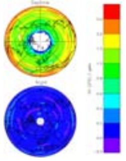

Fig. 7b – OH spatial distribution on January 18, 2006.

Particles events (pfu unit)					OH increase (%)		
Start (Day/UT)	**Maximum** (Day/UT)	**Proton flux** @>10 MeV (5 minutes)	**Proton flux** @>10 MeV (hourly)	**Fluence** @>10 MeV part./(cm² sr)	**~55 km**	**~65 km**	**~75 km**
Nov 01/0655	Nov 01/0805	63	54	1.09E+06			
Nov 07/1910	Nov 08/0115	495	442	1.85E+07	-	99	397
Jan 16/0210	Jan 16/1840	365	332	1.95E+07	76	234	279
Jan 17/1240	Jan 17/1750	5040	4130	2.02E+08	1221	2131	894
Jan 20/0650	Jan 20/0810	1860	1420	6.19E+07	575	1030	448
May 14/0525	May 15/0240	3140	1900	2.87E+07	160	379	328
Jun 16/2200	Jun 17/0500	44	41	1.82E+06			
Jul 14/0245	Jul 15/0345	134	129	1.08E+07			
Jul 27/2300	Jul 29/1715	41	38	9.40E+06			
Aug 22/2040	Aug 23/1045	330	311	2.28E+07	-	93	110
Sep 08/0215	Sep 11/0425	1880	1880	1.65E+08	171	198	104
Dec 06/1555	Dec 07/1930	1980	1940	1.63E+08	110	954	940
Dec 13/0310	Dec 13/0925	698	661	3.68E+07	11	315	543

Tab. 2 – First five columns like Tab. 1; last three columns indicate OH increase (%) for three altitudes.

Fig.s 4 and 5 show the trend of nighttime daily OH radicals in Northern and Southern hemispheres respectively. Events with peak flux of at least 300 pfu (red arrow) cause an OH increase clearly discernible from the background values. Also events with lower flux (blue arrow) seem to induce variability to the mesosphere even if not evident on daily basis. The precision of the zonal average is better than 10% with at least 100 samples up to 0.01 hPa (Pickett et al., 2008, see the number of samples in the lower panel of both figures). The events of January 2005 and December 13, 2006 reached relativistic energies (Ground Level Enhancements) and they induced some limited effects also on the summer hemisphere (Fig. 6). Note the shape of the region influenced by OH increase on Fig. 7a (~20% relative precision). Nighttime OH increases induced by the SEP event of January 17, 2005 and December 8, 2006 are evident roughly inside the Northern polar cap and close to the Southern one (compare with Fig.7b when no SEPs occurred). The left side of Fig. 8 shows the r-values of daily proton flux vs OH increase ($\text{day}_{SEP} - \text{day}_{pre\text{-}SEP}$) for diverse altitudes and energies. The r-values of Fig. 8, right side, are calculated by means of daily OH abundance. We employed 51 days influenced by the SEP events of Tab.2. September 2005 SEPs have been not included because of OH background too high compared with other samples. Two examples of the regression for low energy and elevated altitudes are illustrated in Fig. 9. Note the lower r-values taking into account also days of September 2005 SEPs. Finally Fig. 10 shows the hemispheric differences induced by the September 2005 SEP events (from Damiani et al., submitted). The OH increase recorded on the Northern hemisphere is more intense than the Southern one and reach ~6 ppbv at 0.02 hPa (~75 km, compare with January 2005 in Fig.4).

Conclusions

This work points out the possibility to utilize daily zonal means of OH recorded under nighttime conditions as proxy of almost all SEP events which hit the Earth’s environment. Changes of OH abundance are evident at least up to about 300 pfu. The OH increases connected to SEPs events could be hidden during times of increased air descent inside the polar vortex.

Acknowledgments

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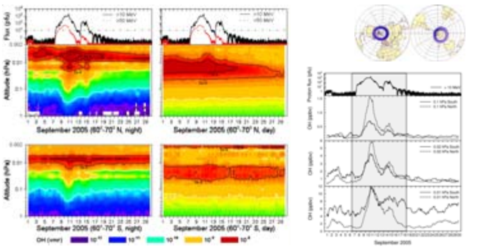

Fig. 10 – Trend of proton flux and zonal means of OH averaged over 60˚-70˚ geomagnetic latitude N&S (color fig.s). OH trend at different altitudes (b/w fig.s). Adapted from Damiani et al., submitted to JASR.

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