Investigation of Minor Components of the Terrestrial Atmosphere related to presence/absence of Solar Energetic Particles

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***Abstract*. We analyzed the ozone, hydroxyl radical and temperature in the middle polar atmosphere, recorded by Microwave Limb Sounder (MLS) onboard the EOS AURA satellite. The gas phase chemical abundances and the temperature during December 2007 (second campaign of IHY/CIP 57) were compared with those retrieved for each December of the years 2004, 2005, 2006 and 2008. Results are illustrated taking into account the presence or lack of Solar Energetic Particles (SEPs) during the investigated periods.**

***Keywords*: AURA satellite data, terrestrial polar atmosphere, minor atmospheric components**

I. INTRODUCTION

In order to characterize the environment of the solar-terrestrial system during the solar activity minimum of cycle 23, two coordinated campaigns (May 31-June 14 and November 30-December 14, 2007) have been performed by the Italian Solar-Terrestrial community inside the IHY/CIP 57. Data from ground based instruments and satellite sensors have been employed. Inside this initiative (IHY/CIP 57, coordinated by M. Storini), in addition to topics strictly connected to the near-Earth environment (e.g. [1] for cosmic rays and solar-interplanetary features), the monitoring of the minor atmospheric components has been achieved. Preliminary results for the second campaign are here discussed, aiming to characterize the middle atmosphere at polar latitudes during the minimum phase of the solar activity cycle 23. More precisely, we extend the investigated period to the entire December 2007, and compare results for this year with those derived from each December between 2004 and 2008.

Figure 1 shows the variability of the following geomagnetic activity indices for December 2007: AE (hourly), Dst (hourly) and Kp (3-h), whose data are available at http://omniweb.gsfc.nasa.gov/); upper panel shows the trend of the proton flux at $>$ 10 MeV from GOES 11 (at http://www.ngdc.noaa.gov/stp/GOES/goes.html). Notice that no solar energetic particle (SEP) events were registered during December 2007.

The presence of SEP events is very important because they can induce variabilities in the middle polar atmosphere trough additional ionization and creation of very reactive components [e.g., HO_x (OH+HO_2) and NO_x (NO+NO_2)] able to reduce the ozone abundance (see [2], among others). Therefore we checked the presence of proton flux enhancements, by using GOES 11 data, during each December of the 2004-2008 time interval. Only in 2006 there are two SEPs, the second one being also a Ground Level Enhancement (GLE 60; e.g. [3]); the $>$ 10 MeV proton flux peaks on 7 and 13 December, respectively. No more SEP events have been found in the investigated periods.

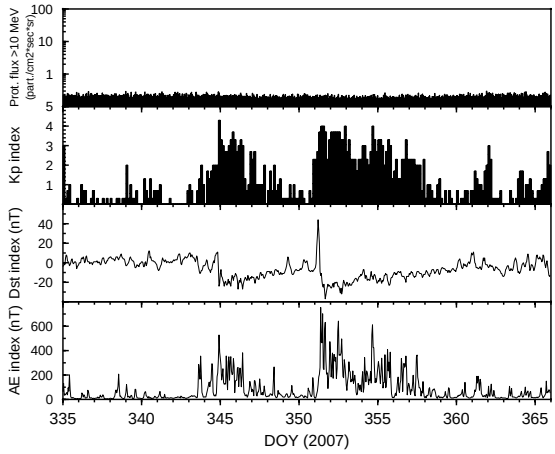

Fig. 1: Time history of some parameters of the Earth environment during December 2007. From bottom to top: AE index, Dst index, Kp index and GOES 11 proton flux at $>$ 10 MeV.

II. DATA USED

Data used were recorded by the Microwave Limb Sounder (MLS) instrument on the AURA satellite. The NASA EOS (Earth Observing System) MLS (see [4]) is one of the four instruments of AURA launched on 15 July 2004 to a sunsynchronous near polar orbit.
MLS scans the Earth's limb in the flight forward direction viewing the microwave emission in different spectral regions. Measurements are performed along the sub-orbital track, and resolution varies for different parameters (typical values are: 5 km cross-track x 500 km along-track x 3 km vertical). The EOS MLS data describe a piecewise linear representation of vertical profiles of gas phase chemical abundances, temperature, and cloud ice density. In this work we will focus on the temperature, O_3 and OH EOS MLS Version 2.2 Level 2 Data (available at http://mls.jpl.nasa.gov/data/) recorded in the geographic latitudinal range 75°-82° North and South, because this region is expected to

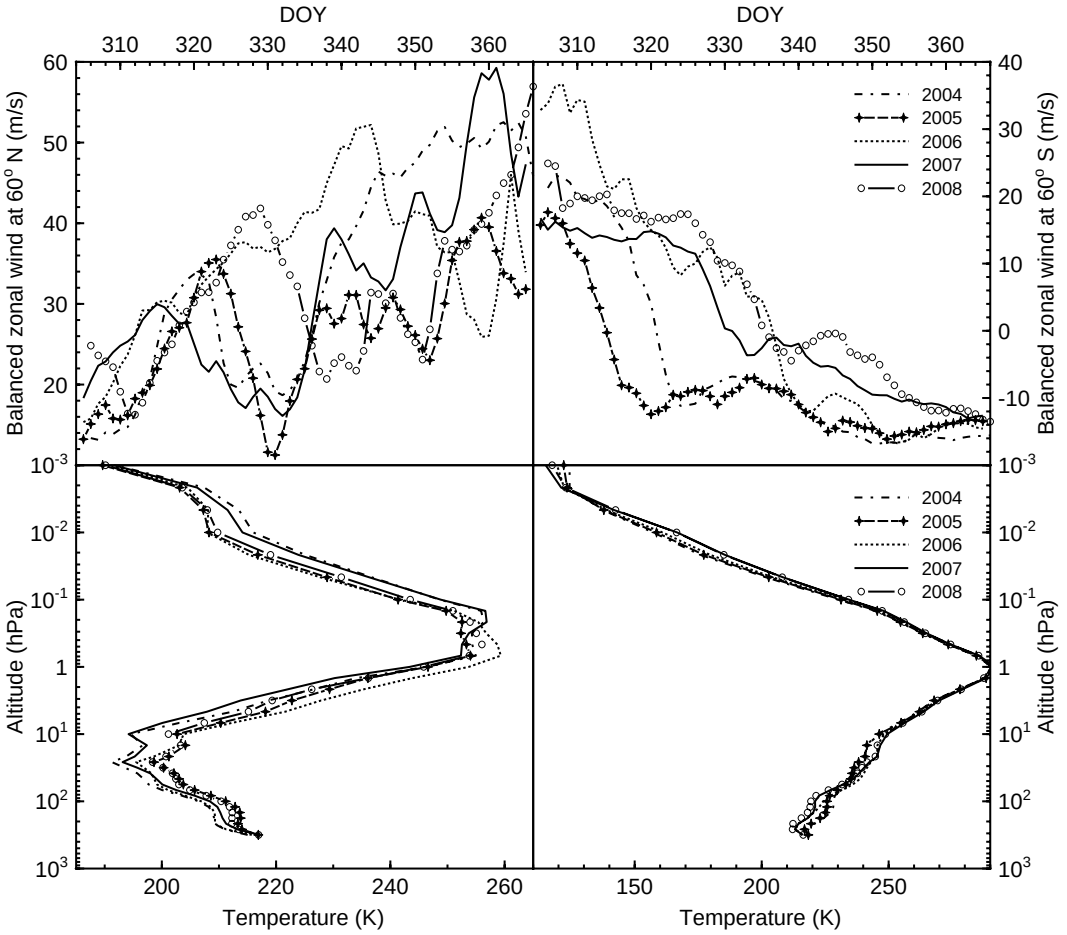

Fig. 2: Balanced zonal wind at latitude 60°N (left upper panel) and 60°S (right upper panel) at 10 hPa from November 1 (305) to December 31 (365/366) of the years 2004-2008; MLS December temperatures in Northern (lower left panel) and Southern (lower right panel) hemisphere.

be representative of the vortex region. The MLS data used in this paper were checked by their data quality (description document: Livesey et al. [5]), in order to ensure the reliability of the obtained results.

III. Results and Discussion

The main feature of the polar middle atmosphere in December is the vortex presence. In this season in the Northern hemisphere it is already formed and is becoming stronger, while in the Southern one it is in its declining phase or at the end. The upper panels of Figure 2 show the balanced zonal winds at latitude 60°N and 60°S and at 10 hPa from NCEP (National Centers for Environmental Prediction) for November-December 2004-2008 (data available at: http://code916.gsfc.nasa.gov/Data_services/met/ann_data.html). This parameter is known to be an important diagnostic tool to monitor the polar vortex intensity. In the Northern hemisphere (Figure 2, left upper panel) the velocity of the eastward stratospheric winds of December 2007 and 2004 seems to rise rapidly compared with that of the other years (i.e., 2005, 2006, and 2008). In addition it is evident the slow decrease of wind values during December 2006 (about 20 m/s in 2 weeks) while the general trend is ascendant.

The lower panels of Figure 2 show the mean MLS temperature profile over the month of December for the years 2004-2008 in the Northern (left) and Southern (right) hemispheres. The error of the mean is $\sim$1 K, reaching maximum values in the stratopause for the Northern hemisphere and $\sim$0.5 K with maxima at about 100 and 0.01 hPa for the Southern one. Although the radiative heating rate at the summer hemisphere is large, the mesospheric air temperature is colder compared with the winter one. The meridional circulation is at the origin of this phenomenon, since at polar latitudes it is upward in summer and downward in winter. In this way the air parcel displaced adiabatically upward undergoes expansion and cooling while downward it undergoes compression and heating (see [6]).

The temperature variability of the Northern hemisphere is almost contained between the values of December 2006 and those of December 2007. The stratosphere in December 2007 was very cold [7] while it was 10-15 K warmer in 2006. On the contrary, the

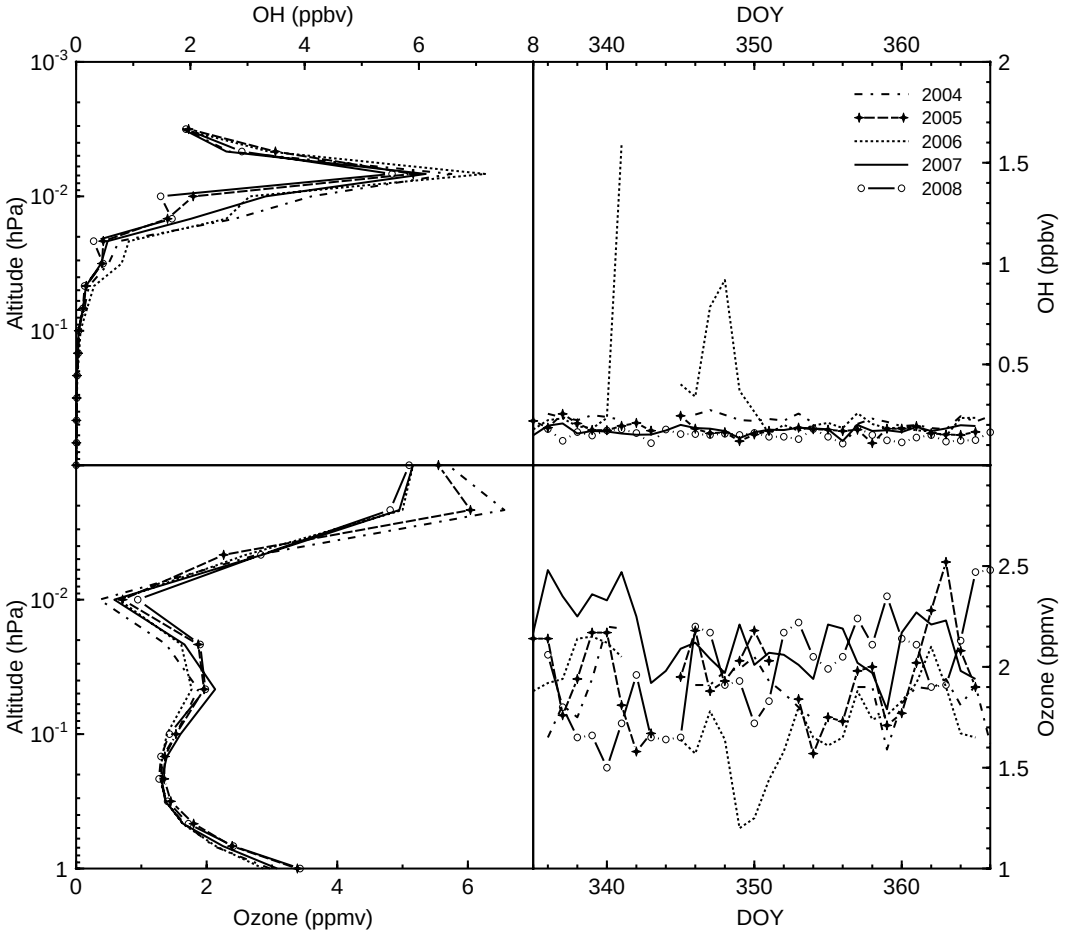

Fig. 3: December MLS ozone (lower left panel) and OH radical (upper left panel) profile for the Northern hemisphere; trend of MLS ozone (lower right panel) and OH (upper right panel) abundance at 0.04 hPa.

mesosphere was cold in 2006 and warm in 2007. The behavior of winds and temperatures seems to induce to a Northern polar vortex stronger and almost stable in 2004 and 2007 (compared with the one for 2006). In this way, less wave activity (i.e. planetary and gravity waves) should be present in December 2004 and 2007 than during December 2006. Wave activity is one of the main elements leading temperature variability in mesosphere (note the low mesospheric temperatures during December 2006 and the high ones during December 2004 and December 2007).

The lower left panel of Figure 3 shows the mean profile of MLS ozone in December in the Northern hemisphere (the error of the mean is $< 5\%$ for both hemispheres). Note the higher values of December 2007 close to third ozone peak ($\sim$ 0.04 hPa) and the lower values during December 2006 (Figure 3, lower right panel). The low values of December 2006 are related to the rise of mesospheric HO_x caused by the presence of the two SEP events, as reported in the Introduction. The upper left panel of Figure 3 shows higher values of the mean profile of MLS OH radical in December 2006. Therefore a strong anti-correlation between low ozone values and high OH radicals abundance is present at 0.04 hPa (Figure 3, upper right panel; see [8] for a detailed analysis of MLS data under SEP conditions).
The vortex break up is a very important feature of the middle atmosphere at the Southern polar latitudes during December. The balanced zonal winds at latitude 60°S and at 10 hPa (Figure 2, top - upper right panel) show that the end of the vortex in stratosphere during 2004 and 2005 happens in November while for 2006, 2007 and 2008 in early-mid December. A similar trend is expected in mesosphere and accordingly we can expect a different behavior of the monthly temperature (Figure 2, lower right panel). The upper panel of Figure 4 shows the December MLS temperature deviation from its average temperature for 2004-2008 period. Note the different behavior of 2004 and 2005 compared with the ones for 2007 and 2008. To notice that December 2006 temperature of the Southern hemisphere has been likely influenced by SEP events. Therefore we should expect temperature variability in upper and lower mesosphere due to Joule heating and ozone depletion respectively (e.g., [9]). That will be the subject of a next paper.

Finally the middle and lower panels of Figure 4

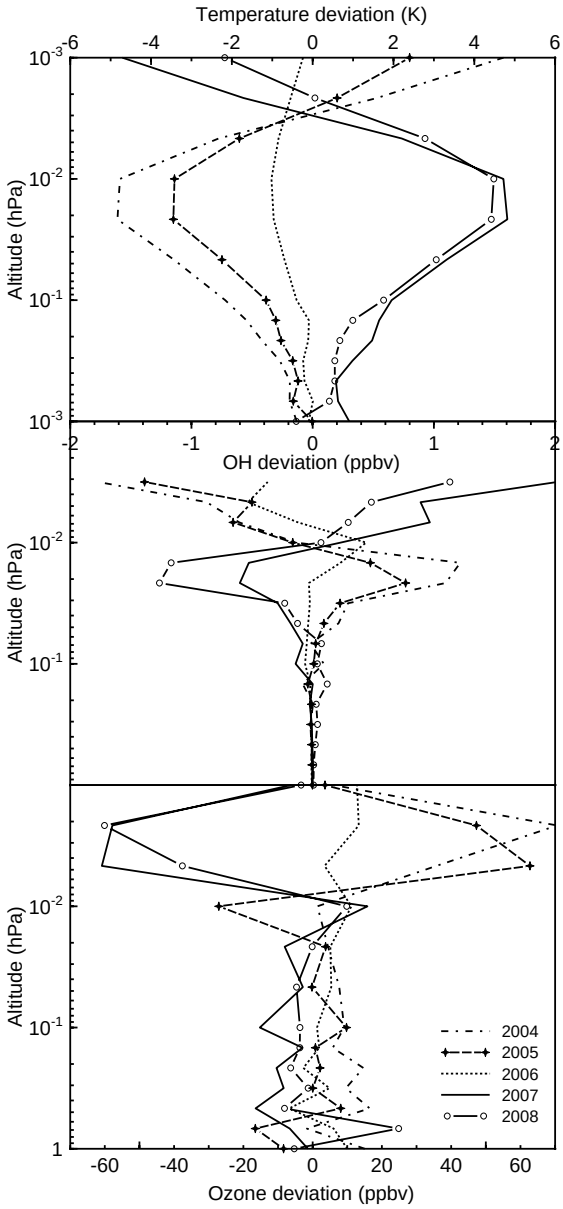

Fig. 4: From top to bottom: December MLS Temperature, OH and Ozone deviation from their average evaluated from the 2004-2008 period (years as in Figures 2 and 3).

show the mean profile of December for ozone and OH radicals in the Southern hemisphere, reported as deviation from their mean. Note the control of the temperature on the trend of the chemical abundances.

IV. Conclusions

This work shows a preliminary characterization of the middle polar atmosphere in December 2007 (in comparison with the years 2004-2008) when low geomagnetic activity and no SEP events were present. Some atmospheric features of December 2007 are listed below.

- *Northern hemisphere:*
  - elevated stratospheric zonal wind velocity compared with general trend;
  - unusual low temperature in stratosphere;
  - warm temperature in mesosphere;
  - low standard deviations of daily temperatures (not shown);
  - high values of the third ozone peak.

- *Southern hemisphere:*
  - late breakup of the polar vortex;
  - warm temperatures in stratosphere and mesosphere;
  - cold temperatures in mesopause;
  - elevated OH and H_2O (not shown) values in the upper mesosphere;
  - low ozone values in mesosphere.

The performed work and the derived *short climatology* should be useful for a better evaluation of SEP impact on the terrestrial environment, particularly to take into account their relationship with Space Weather issues.

Acknowledgements

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References

[1] M. Storini et al., *Cosmic rays during IHY/CIP 57*, in Kudela et al. (eds.), Proc. 21th ECRS (Kosice, Sept. 9-12, 2008), in press (available in the CD-2008 version), 2009.

[2] C.H. Jackman et al., *Short- and medium-term atmospheric constituent effects of very large solar proton events*, Atmos. Chem. Phys. 8, 765-785, 2008.

[3] M. Storini et al., *The December 2006 GLE Event as seen from LARC, SVIRCO and OLC*, Proc. 30th Int. Cosmic Ray Conf., Vol. 1, pp. 273-276, 2008.

[4] J.W. Waters et al., *The Earth Observing System Microwave Limb Sounder (EOS MLS) on the Aura satellite*, IEEE TGARS 44, 1075-1092, 2006.

[5] N.J. Livesey et al., *Earth Observing System (EOS) Microwave Limb Sounder (MLS) Version 2.2 Level 2 data quality and description document*, Report JPL D-33509, Version 2.2x-1.0a, Jet Propulsion Laboratory, California Institute of Technology, Pasadena (Ca), 2007.

[6] G.P. Brasseur, and S. Solomon, *Aeronomy of the Middle Atmosphere*, Springer, Dordrecht, 3rd revised and enlarged edn., 2005.

[7] S. Kirkwood et al., *A new height for the summer mesopause: Antarctica, December 2007*, Geophys. Res. Lett., 35, L23810, doi:10.1029/2008GL035915, 2008.

[8] A. Damiani et al., *Solar particle effects on minor components of the Polar atmosphere*, Ann. Geophys. 26 (2), 361-370, 2008.

[9] C.H. Jackman et al., *Mesospheric dynamical changes induced by the solar proton events in October-November 2003*, Geophys. Res. Lett. 34, L04812, doi:10.1029/2006GL028328, 2007.