Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 277–280

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Effects of the January 2005 GLE/SEP events on minor atmospheric components

M. STORINI[1], A. DAMIANI[2].
[1]*Istituto di Fisica dello Spazio Interplanetario - INAF, Via del Fosso del Cavaliere, 100 - 00133 Roma, Italy*
[2] *ICES - International Center for Earth Sciences c/o CNR Istituto di Acustica "O.M. Corbino", Via del Fosso del Cavaliere, 100 - 00133 Roma, Italy*
storini@ifsi-roma.inaf.it

Abstract: It is known that solar energetic charged particles, driven by the geomagnetic field, are able to produce ionization at different altitudes of the terrestrial atmosphere. Moreover, they can initiate catalytic cycles for the ozone depletion, involving NO_x (N, NO, NO_2) and HO_x (H, OH, HO_2) components. Nevertheless, only in recent years it has been possible to compare chemical models involving atmospheric minor components with satellite data. In this work we look for effects of the GLE/SEP events occurred during January 2005 on the OH and HNO_3 species of the atmosphere. Results show that the response of the minor atmospheric components is different in the winter and summer terrestrial hemispheres.

Introduction

It is widely known that minor atmospheric constituents are strongly dependent on the geomagnetic and solar activity. In particular, several effects induced by cosmic rays (CRs) can be singled out at diverse altitudes. For example, in the troposphere the CR flux seems to be connected to the cloud formation ([1] for an early work and [2] for a recent analysis) and in the lower stratosphere CRs are an important source of nitric oxide (NO) molecules, by the ionization and dissociation of the molecular nitrogen (N_2). During the polar winter the lack of sunlight prevents the formation of NO via the reaction of nitrogen protoxide (N_2O) with atomic oxygen. In these condition CR flux could be the main source of nitric oxide [3]. Besides solar energetic particle (SEP) events are able to trigger catalytic cycles of O_3 destruction in stratosphere and mesosphere [4].

During January 2005, after a low/moderate solar activity, a big injection of solar energetic particles in the terrestrial atmosphere occurred ($\sim$ 16-22 January). Two Ground-Level Enhancements were identified (GLE68/SEP: 17 January, start $\sim$ 10 UT and GLE69/SEP: 20 January, start $\sim$ 07 UT) by the world-wide network of cosmic ray detectors. This paper focuses on the January 2005 GLE/SEP effects on the polar atmospheric chemistry.

Used Data

Atmospheric data from the Micro-wave Limb Sounder (MLS) instrument on the AURA satellite are used. The NASA EOS (Earth Observing System) MLS is one of the four instrument of AURA launched on 15 July 2004 to sun-synchronous near polar orbit.

The MLS instrument scans the Earth's limb observing the microwave emission in different spectral regions. The measured chemical components are: O_3, H_2O, BrO, ClO, HCl, HOCl, OH, HO_2, HCN, CO, HNO_3, N_2O, and SO_2 mixing ratios.

In this work EOS MLS Version 1.5 Level 2 Data is used (http://mls.jpl.nasa.gov/data/), from which O_3, HNO_3, and OH values were taken. The proton flux was retrieved from GOES 11 files (http://www.ngdc.noaa.gov/stp/GOES/).

January 2005 GLE/SEP events

SEP events are able to produce ionization at different altitudes of the terrestrial environment and

can initiate catalytic cycles for the ozone depletion, involving NO_x (NO, NO_2) and HO_x (OH, HO_2) components. Such effects generally refer to the Polar Cap regions (geomagnetic latitudes above 60°). Nevertheless, [5] showed that January 2005 GLE/SEP events produced also two weak and very short ($<$ 12 h) ozone depletions at the external boundary of the Southern Polar Cap.

Moreover, Damiani et al. [6], analyzing the interhemispheric differences, emphasized that at Southern high latitudes (day state) the O_3 decrease is weak while in the Northern (night state) ones it is strong and long lasting, particularly in the mesosphere. For this reason, Figure 1 (upper panel) displays only the daily ozone profiles in the Northern Hemisphere (location: $\sim$ 75°-82°), before and after the GLE/SEP events of January 2005. The elevate values of the mesospheric O_3 mixing ratio on the day before the event (blue profile) are related to the existence of a third ozone maximum during the winter time [7]. In fact, at high latitudes of the winter hemisphere the low sunlight leads to a minor efficiency of the UV flux on the water vapour photolysis. Therefore, the reduced production of HO_x components in "night" condition facilitates the increase of the ozone concentration. Mesospheric ozone depletion (more than 1 ppmv) is evident on 18 January (the day after the first GLE/SEP) lasting for some days. In the stratosphere (above 1 hPa) the ozone decrease is less evident from the daily profiles; an analysis of NO_x component should be performed. The MLS instrument cannot measure atmospheric NO_x but it is able to retrieve nitric acid, a good proxy for NO_y (reservoir nitrogen). During January 2005 SEPs, along with stratospheric ozone depletion, an HNO_3 increase appears between 10 and 2 hPa ($\sim$ 30-40 km), persisting till the end of the month. Figure 1 (lower panel) shows its temporal evolution (location: $\sim$ 75°-82° N) by using derived HNO_3 (mixing ratio) contours, from 15 to 31 January 2005. This increase of nitric acid can originate from two different processes.

The first process involves the most important HNO_3 production phenomenon:

$NO_2 + OH + M \rightarrow HNO_3 + M.$

Therefore, the HNO_3 increase can be the result of the OH and NO_2 raise during SEPs; this reaction is fast enough to produce the amount of nitric acid

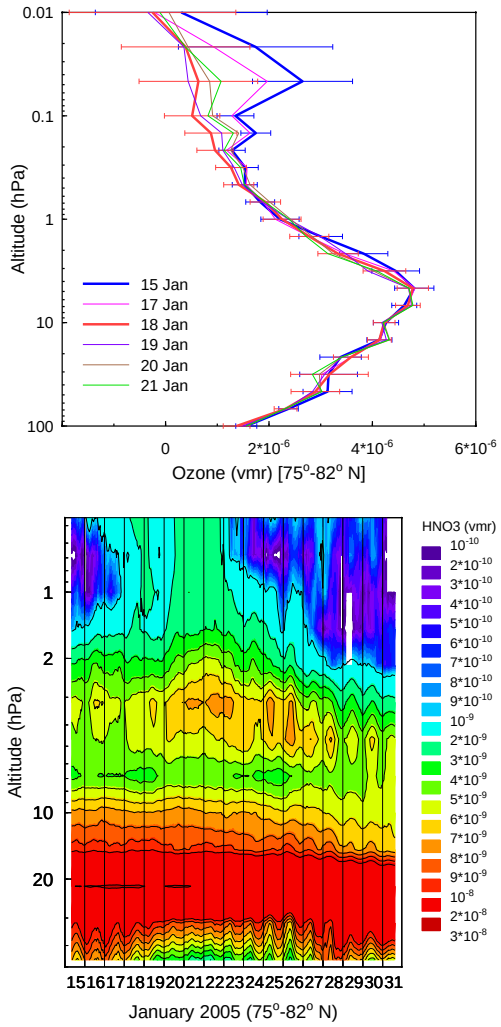

Figure 1: Daily ozone profile of averaged values (volume mixing ratio) during several days of January 2005 (upper panel) and contours of averaged HNO_3 (volume mixing ratio) values during the second part of January 2005 (lower panel). Selected location: $\sim$ 75°-82° N.

similar to that observed during October-November 2003 GLE/SEP events [8].

The second process is related to the ion chemistry [9] and may be important since it is an active process also during night time (i.e. winter hemisphere at elevate latitudes). Through the reaction of water cluster ions with NO_3 the nitric acid is able to raise. Nevertheless, the elevate photolysis at the summer hemisphere prevents to single out the HNO_3 variability for the January GLE/SEPs.

During January 2005 GLE/SEP events it was possible also to highlight the increase of the OH molecules (proxy for HO_x) associated with the SEP transit in the atmosphere. Figure 2 shows the OH temporal evolution for $\sim$ 75°-82° N (upper panel) and S (lower panel) for 15-24 January 2005. The sudden and intense OH enhancement evidences the goodness of expectations from available models. The OH concentration raises several hundreds of % at Northern latitudes, whereas it remains almost constant at Southern ones (only a weak modulation is present). Here the intense solar illumination increases the OH background values and hides the induced effects by SEPs. It is worthwhile to notice that the response of odd hydrogen species to SEPs is very fast, almost contemporary, either in summer or winter hemisphere.

Summary and conclusions

GLE/SEP effects induced on some minor components of the terrestrial atmosphere have been illustrated for the GLE/SEP events occurred during January 2005. Results for a Polar Cap location ($\sim$ 75°-82°) can be summarized as follows:

- A relevant increase of the HNO_3 from 19 to 28 January 2005 is identified from $\sim$ 2.5 hPa to 5.5 hPa at the Northern hemisphere (Figure 1, lower panel).
- The OH increase during the GLE/SEP events presents a fairly good correspondence with the proton flux profile in the Northern hemisphere (Figure 2, upper panel).

Moreover, in the upper mesosphere ($\sim$ 60-80 km) the OH variability seems to be triggered by a cut-off value in the proton flux ($\sim$ 10 pfu for particle

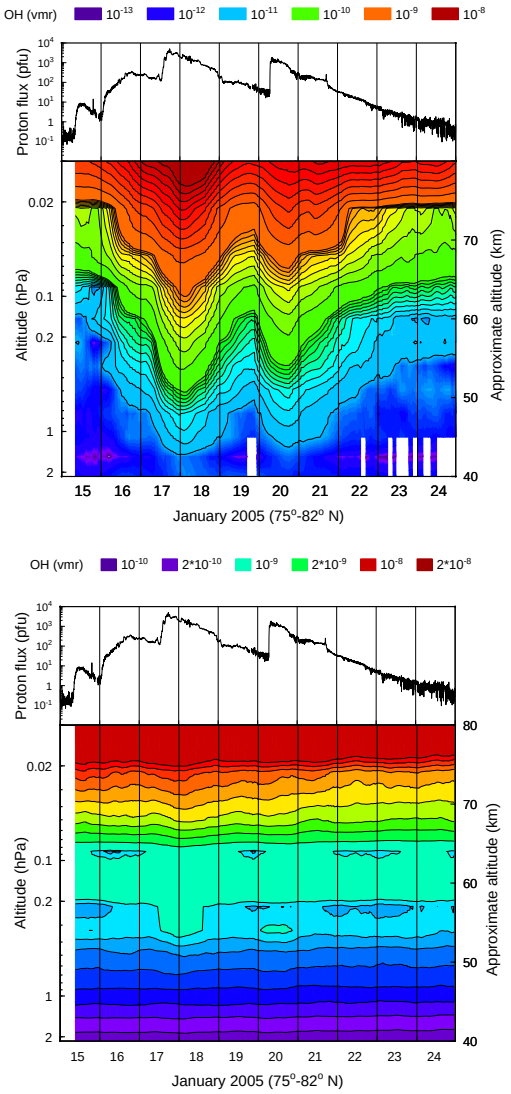

Figure 2: Solar proton flux (particle energy E > 10 MeV) from GOES 11 data and contours of OH values (volume mixing ratio) from MLS/EOS data for $\sim$ 75°-82° N (upper panel) and $\sim$ 75°-82° S (lower panel).

energy E $>$ 10 MeV). In fact, the SEP flux arriving on the terrestrial environment on 16 January initiated the OH modulation, which is ended when the proton flux went below $\sim$ 10 pfu. This behaviour is less evident in the Southern hemisphere (Figure 2, upper panel). In the lower mesosphere the scenario is more complex.

In conclusion, it is stressed that the high OH values under solar illumination make difficult to single out the OH rise induced by SEPs, since the background concentration of H-species depends on the H_2O concentration (more elevated in the summer mesosphere). On the contrary, the reduced solar illumination during the winter time facilitates to highlight the atmospheric chemistry changes. Moreover, in the winter hemisphere the OH changes are long lasting (if compared with the summer ones, because of the OH short life under solar light). Very probably, the different OH concentration and life during the extreme seasons is the main reason for the elevated and long lasting O_3 depletion in the Northern mesosphere and the short and feeble O_3 decrease at the Southern one.

Acknowledgements

Work faced for COST 724 Action, supported by the Italian PNRA and partly performed for a PhD thesis under development at Siena University/Dept. of Earth Science.

References

[1] H. Svensmark, E. Friis-Christensen, Variations of cosmic ray flux and global cloud coverage: a missing link in solar-climate relationships, Journal of Atmospheric and Solar-Terrestrial Physics 59 (1997) 1225–1232.

[2] I. G. Usoskin, M. Voiculesku, G. A. Kovaltsov, K. Mursula, Correlation between clouds at different altitudes and solar activity: Fact or Artifact, Journal of Atmospheric and Solar-Terrestrial Physics 68 (2006) 2164–2172.

[3] M. Nicolet, On the production of nitric oxide by cosmic rays in the mesophere and stratosphere, Planetary and Space Science 23 (1995) 637–649.

[4] P. J. Crutzen, I. S. A. Isaksen, G. C. Reid, Solar proton events: Stratospheric source of nitric oxide, Science 189 (1975) 457–458.

[5] A. Damiani, M. Storini, M. Laurenza, C. Rafanelli, E. Piervitali, E. G. Cordaro, Southern ozone variations induced by solar particle events during 15 January-5 February 2005, Journal of Atmospheric and Solar-Terrestrial Physics 68 (2006) 2042–2052.

[6] A. Damiani, M. Storini, M. Laurenza, P. Diego, C. Rafanelli, Search for the ozone variability related to SEP events during the current solar cycle, Submitted to Journal of Advances in Space Research.

[7] D. Marsh, A. Smith, G. Brasseur, M. Kaufmann, K. Grossmann, The existence of a tertiary ozone maximum in the high-latitude middle mesosphere, Geophysical Research Letters 28 (2001) 4531–4534.

[8] M. López-Puertas, B. Funke, S. Gil-López, T. von Clarmann, G. P. Stiller, M. Hoepfner, S. Kellmann, G. Mengistu Tsidu, H. Fischer, C. H. Jackman, HNO3, N2O5, and ClONO2 enhancements after the October-November 2003 solar proton events, Journal of Geophysical Research 110 (2005) A09S44.

[9] S. Solomon, D. V. Rusch, J. C. Gérard , P. J. Crutzen, The effect of particle precipitation events on the neutral and ion chemistry of the middle atmos-phere: II. Odd hydrogen, Planetary and Space Science 29 (1981) 885–893.