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Effect of solar protons on the middle atmosphere composition during GLE 13 December, 2006

A.S. KIRILLOV[1], YU.V. BALABIN[1], E.V. VASHENYUK[1], KH. FADEL[2], L.I. MIROSHNICHENKO [3, 4]
[1]*PGI, Apatity, Murmansk Region, 184209, Russia*
[2]*Swedish Institute of Space Physics, Umed University, Sweden*
[3]*Instituto de Geofisica, UNAM, C.U., Coyoacan, 04510, Mexico D.F., Mexico*
[4]*IZMIRAN, Troitsk, Moscow Region, 142190, Russia*
kirillov@pgi.kolasc.net.ru

Abstract: The effect of energetic solar protons on the middle atmosphere (20-80 km) chemical composition during the SPE 13 December, 2006 has been studied. The solar proton spectra were obtained from the neutron monitors, balloons and spacecraft data. One-dimensional time-dependent model (Fadel et al., 2006, Adv. Space Res., v.38, p.1881-1886) has been used to calculate the production and loss of minor atmospheric components during the GLE. Derived depletions of ozone content is in good agreement with experimental data obtained by the Microwave Limb Sounder (MLS) instrument on the AURA spacecraft.

Introduction

Solar protons interacting with main atmospheric components N_2 and O_2 at altitudes of the middle and lower atmosphere take part in processes of ionization, dissociation, dissociative ionization etc. Following chemical reactions in the atmosphere cause the production of large amounts of odd-nitrogen and odd-hydrogen. The odd-nitrogen NO_x and odd-hydrogen HO_x molecules influence on ozone content in the mesosphere and stratosphere through the catalytic cycles (including NO + NO_2 and H + OH + HO_2) [1]. The depletion of ozone layer in the middle atmosphere during intensive solar proton events (SPE) of past decades in August 1972, October 1989, July 2000, October 2003 was studied in [2-6, respectively]. Recent study of the solar proton effect on minor atmospheric components during the January 2005 GLE/SEP events was performed in [5].

The main goal of this paper is to study ozone concentration depletions observed in the middle atmosphere during SPE series in December 2006. Here we shall follow the "traditional" point of view in the calculation of the odd-nitrogen and odd-hydrogen effect on the ozone balance. Any effect of electronically excited molecules on ozone content during SPE discussed by Kirillov [7] is not included in this study.

Chemical model of the middle atmosphere

Our model of the middle atmosphere (20-80 km) for quiet and disturbed conditions is described in [4]. Here we include in the model following minor components: atomic oxygen $O(^3P,^1D)$, ozone O_3, atomic nitrogen $N(^4S,^2D)$, odd-nitrogen NO_x (nitric oxide, nitrogen dioxide and trioxide), dinitrogen pentoxide N_2O_5, nitrous oxide N_2O, odd-hydrogen HO_x (atomic hydrogen, hydroxyl and hydroperoxy radicals), even-hydrogen H_2O_x (molecular hydrogen, water vapor, hydrogen peroxide) HNO_x (nitrous, nitric and peroxynitric acids), CO_x (carbon monoxide and dioxide), CH_x (methyl and methane), CH_xO_y (formyl radical, formaldehyde, methoxy and methylperoxy radicals, methyl hydroperoxide), chlorine and bromide compounds: X_2, X, HX, HOX, XO, $XONO_2$ (here X=Cl or Br), asymmetric ClOO and symmetric OClO chlorine dioxides, chlorine oxides Cl_2O_x (x=1-3), BrCl. 137 chemical reactions between the components and absorption cross sections for solar light are taken according to [8, 9]. The rates of ion-electron pair production by solar protons at different altitudes were calculated with a relation from [10]. Then the continuity non-stationary equations were solved for minor components of the middle atmosphere. The production and loss rates include the contributions from dissociative processes connected with solar light inelastic scattering, chemical reactions, as well as production of minor components in collisions of protons and secondary electrons with main atmospheric components. Upper and lower borders in our calculation are at 80 and 20 km, respectively. Border conditions were given by fluxes at 80 km and photochemical equilibrium at 20 km. The time integration of continuity equations were carried out explicitly. In this case the spatial derivative terms are only evaluated at known time (preceding step in time) [11]. Time and altitude steps for integration in our calculation were 0.1 sec and 1 km, respectively.

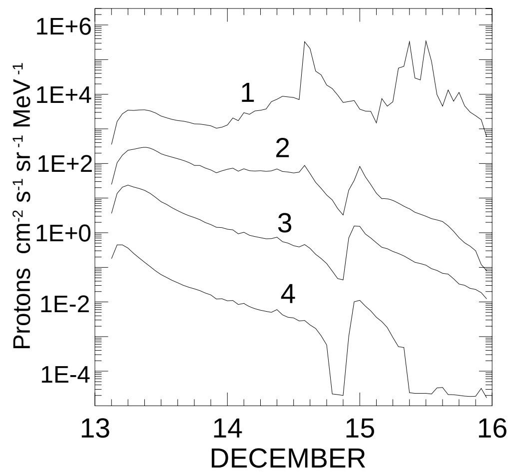

Figure 1: Intensity profiles of solar protons with energies 1, 9, 40 and 165 MeV (curves 1-4, respectively) for 13-15 December, 2006.

Energy spectra of solar protons

Ionization effects in the middle atmosphere during the period 13-15 December, 2006 were caused by the GLE of 13 December and soft proton increase on 14 December related with interplanetary shock wave arrival. Fig. 1 shows intensity profiles of solar protons with energies 1, 9, 40 and 165 MeV as measured by GOES-11 spacecraft. The differential energy spectra derived for 4 moments of time (06 UT on December 13, 14 UT on December 14, 00 and 08 UT on December 15) are shown in Fig.2.

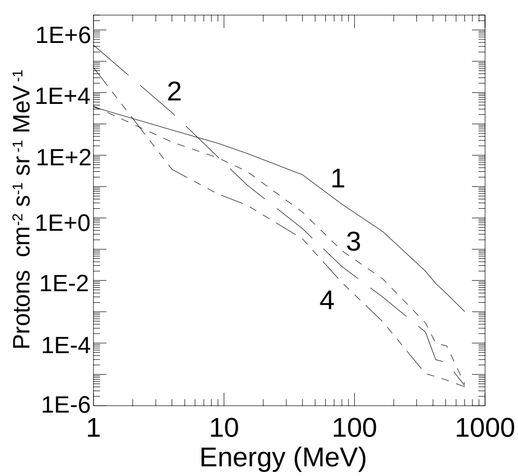

Figure 2: Differential energy spectra of solar protons for 4 moments of time: 1- 13.12, 06 UT, , 2- 14.12, 14 UT, , 3- 15.12, 00 UT and 4- 15.12, 08 UT.

Fig. 3 shows the ionization profiles calculated using energetic spectra (Fig.2) and relations for ion-electron pair production rates by solar protons [4, 10]. The profile 1 corresponds to the ionization state during the first maximum after SPE onset. Profile 2 corresponds to the intensity peak of low energy protons related to coming interplanetary shock. The profile 3 is calculated for the moment of intensity maximum late on 14.12. The profile 4 is calculated at the moment of the secondary soft proton increase on 15.12 (Fig.1).

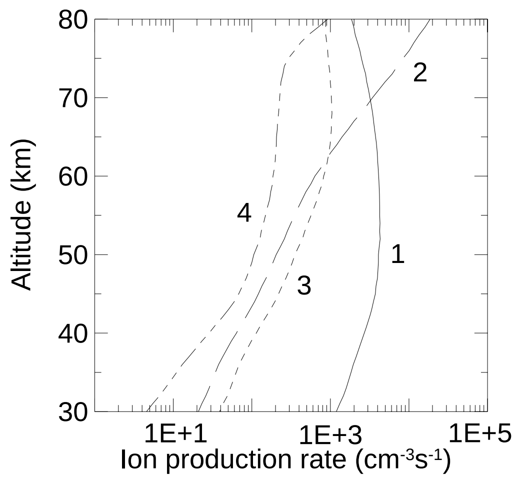

Figure 3: Profiles of ion production rates calculated using spectra presented in Fig.2.

Results of calculation and comparison with experimental data

Altitude profiles of O_3 concentration measured by the Microwave Limb Sounder (MLS) instrument on the AURA satellite on 12 and 16 December 2006 are shown in Fig.4. These altitude profiles were obtained at the point (70°N and 150°E).

Our simulations for 12 and 15 December (before SPE and during SPE in progress) are compared here with MLS measurements. We suggested in the calculations that in the middle atmosphere the odd-nitrogen and odd-hydrogen produced per ion-electron pair has the ratios of 1.3 and 2.0, respectively [12-14]. As quiet conditions we have taken the initial ozone profile in accordance with mesospheric measurements of [15, 16]. Our simulation shows that visible ozone depletion is significant at atmospheric pressure levels of 2-3 mb and less. The spacecraft measurements showed the ozone depletion in a layer from 4 to 0.6 mb (Fig. 4) which qualitatively agrees with our calculations .

The processes of the ionization and odd-nitrogen and odd-hydrogen production are very effective only at atmospheric pressures less than a few mb for isotropic angular distribution of solar protons. The calculations of altitude profiles of atmospheric components have shown that the obtained decrease in ozone concentrations is caused by the OH production.

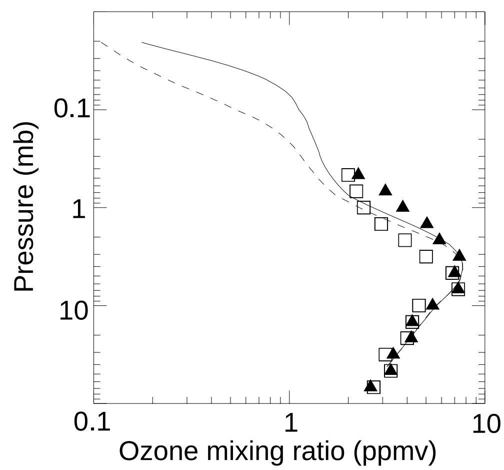

Figure 4: Ozone profiles observed by MLS instrument on the AURA spacecraft on 12 and 16 December (triangles and squares, respectively) and calculated for 02 UT of 12 and 15 December (solid and dashed lines, respectively).

Conclusions

Here we have applied the one-dimensional time-dependent model of the middle atmosphere to estimate the changes in atmospheric ozone content during SPEs on 13-15 December, 2006. Our calculations have shown that the main factor causing the ozone content decrease in the middle atmosphere during solar proton precipitations is the odd-hydrogen species production through the multiple hydrogen and subsequent recombination in the ionization products.

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References

[1] Brasseur G., Solomon S. Aeronomy of the middle atmosphere. Dordrecht, Holland, (1984).

[2] Reagan J.B., Meyerott R.E., Nightingale R.W. et al. Effects of the August 1972 solar particle events on stratospheric ozone. // J. Geophys. Res., 86, 1473-1494 (1981).

[3] Jackman C.H., McPeters R.D., Labow G.J. et al. Nothern hemisphere atmospheric effects due to the July 2000 solar proton event. // Geophys. Res. Lett., 28, 2883-2886 (2001).

[4] Fadel Kh., Vashenyuk E.V., Kirillov A.S. Ozone depletion in the middle atmosphere during solar proton events in October 2003. // Adv. Space Res., 38, 1881-1886 (2006).

[5] Storini M., Damiani A. Effects of the January 2005 GLE/SEP events on minor atmospheric components. 30 ICRC, Paper SH 1009 (2007).

[6] Zadorozhny A.M., Kikhtenko V.N., Kokin G.A. et al. Middle atmosphere response to the solar proton events of October 1989 using the results of rocket measurements. // J. Geophys. Res., 99, 21059-21069 (1994).

[7] Kirillov A.S. Production of singlet oxygen in Earth atmosphere during solar proton precipitations. // Ekological chemistry, 13, 69-78 (2004).

[8] Atkinson R., Baulch D.L., Cox R.A. et al. Summary of evaluated kinetic and photochemical data for atmospheric chemistry. IUPAC Subcommittee on gas kinetic data evaluation for atmospheric chemistry, (2005).

[9] Sander S.P., Friedl R.R., Golden D.M. et al. Chemical kinetics and photochemical data for use in atmospheric studies, JPL Publication 02-25, JPL, Pasadena, CA (2003).

[10] Dorman L.I. Experimental and Theoretical Background of Astrophysics of Cosmic Rays. Nauka, Moscow, (1975) (in russian).

[11] Rood R.B. Numerical advection algorithm and their role in atmospheric transport and chemistry models. // Rev. Geophys., 25, 71-100 (1987).

[12] Heaps M.G. The production rates of odd-hydrogen and odd-nitrogen species for ionizing events in the mesosphere and upper stratosphere. // Eos Trans. AGU, 59, 341 (1978).

[13] Solomon S., Rusch D.W., Gerard J.-C., et al. The effect of particle precipitation events on the neutral and ion chemistry of the middle atmosphere: II. Odd hydrogen. // Planet. Space Sci., 29, 885-892 (1981).

[14] Rusch, D.W., Gerard, J.-C., Solomon, S., Crutzen, P.J., Reid, G.C. The effect of particle precipitation events on the neutral and ion chemistry of the middle atmosphere: I. Odd nitrogen. // Planet. Space Sci., 29, 767-774 (1981).

[15] Rusch D.W., Mount G.H., Barth C.A. et al. Ozone densities in the lower mesosphere measured by a limb scanning ultraviolet spectrometer. // Geophys. Res. Lett., 10, 241-244 (1983).

[16] Solomon S., Rusch D.W., Thomas R.J. et al. Comparison of mesospheric ozone abundances measured by the Solar Mesosphere Explorer and model calculations. // Geophys. Res. Lett., 10, 249-252 (1983).