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THE IONIZATION OF THE EARTH'S ATMOSPHERE AND OZONE LAYER'S VARIATIONS AFTER SOLAR PROTON EVENTS DURING JANUARY 2005

I. N. Myagkova[a], A.V. Kukoleva[b], A.A. Krivolutsky[b], T.Yu. Vyushkova[b], A.A.Kuminov[b]

[a] *Scobeltsyn Institute of Nuclear Physics, MSU, Moscow* [b] *Central Aerological Observatory Dolgoprudny, Moscow Region*

Abstract. The calculation results of ionization and ozone layer response variations in polar regions of atmosphere of the Earth at altitudes from zero to 120 km caused by solar protons, generated in the flares occurring on the Sun in second half of January, 2005 are presented. Differential spectra of solar protons were calculated according to GOES-10 and CORONAS-F satellites data.

Solar flares produce the intensive fluxes of high-energy protons and strongly influence on the near-Earth environment and Earth's atmosphere. Solar protons penetrating into high latitudes in the Earth's atmosphere cause its ionization and transform its chemical compound. The response of an ozone layer on additional NOx and HOx manufacture the middle atmosphere depends not only on solar protons intensity, but also on solar particle spectrum, and modeling of the processes in atmosphere of the Earth, based on experimental data about flux and spectra of solar particles is an actual problem.

It was shown that solar proton events of January 2005 have strongly influenced a condition of high-altitude atmosphere of the Earth. The obtained results of the modeling based on the polar low-altitude satellite CORONAS-F data (which was during the considered period at altitude about 400 km) are significantly differ in comparing with ones based on the data of geostationary satellite GOES-10. It is probably caused by distinction of observable fluxes and spectra of protons (in particular with 1-5 MeV energy) at the geostationary orbit and at low (400-500 km) altitudes.

1. Introduction

Charged energetic particles produced in solar flares and accelerated in solar atmosphere or/and in interplanetary space penetrate the atmosphere of the Earth *inside polar caps*. These particles influence on chemical composition of the middle atmosphere. Additional NO_X (N, NO, NO_2) and HO_X (H, OH, HO_2) minor compounds are produced after ionization of the air by solar energetic particles. Each pair of ions gives about two molecular of HO_X [Solomon et al., 1981] as a result of ion chemistry, and 1.25 NO_X [Porter et al., 1976]. Then appeared chemical constituents can be able to destroy ozone in following catalytic cycles:

$$\mathbf{NO + O_3 \rightarrow NO_2 + O_2}$$
$$\underline{\mathbf{NO_2 + O \rightarrow NO + O_2}}$$
$$\mathbf{Net:\quad O_3 + O \rightarrow O_2 + O_2},$$

and

$$\mathbf{OH + O \rightarrow H + O_2}$$
$$\underline{\mathbf{H + O_3 \rightarrow OH + O_2}}$$
$$\mathbf{Net:\quad O + O_3 \rightarrow 2O_2}.$$

Due to the configuration of the Earth's magnetic field solar protons primarily precipitate in the polar caps, and Solar Proton Events (SPEs) mostly cause chemical changes in both polar regions, except the situations of a magnetic field polarity transition [Sinnhuber et al., 2003]. It possibly leads to the possibility for solar protons after SPEs cause global effects in the composition of the atmosphere.

The lifetime of HO_X is only the order of hours in the stratosphere and mesosphere and we need a constant source of HO_X to accumulate long-term effect in ozone. At the same time NO_X "family" has very long lifetime, and so, may cause long-term effects in ozone layer. SPE-induced changes in ozone lead to changes in dynamics and temperature as 3D model runs showed [Krivolutsky et al., 2006].

In this paper we present some results model photochemical simulations, which illustrate the response of ozonosphere of the Earth to Solar Proton events that occurred during the second half of January 2005.

2. Ionisation of polar atmosphere after SPEs

Ionisation rates caused by solar protons for selected SPEs during 2000-2003 have been calculated using the method described by [Vitt and Jackman, 1996]. It was supposed that considered latitudes are always placed inside the polar cap regions. As an example of the solar protons influence on the Earth's atmosphere the rates of the ionization calculated for SPE 2000.07.17 are shown in Fig.1. One can see that the data about solar proton spectrum are very important for the calculations of atmosphere ionization by solar protons.

We can see than the maximal ionization is caused by the protons with the energies about 40 MeV at altitudes 50-70 km, protons with the energies about 100 MeV penetrate deeper in the Earth's atmosphere (40-50 km), but the rate of ionization due to them significantly lower, and even the protons with the energies less then 20 MeV can cause the Earth's atmosphere ionization at latitudes 60-80 km.

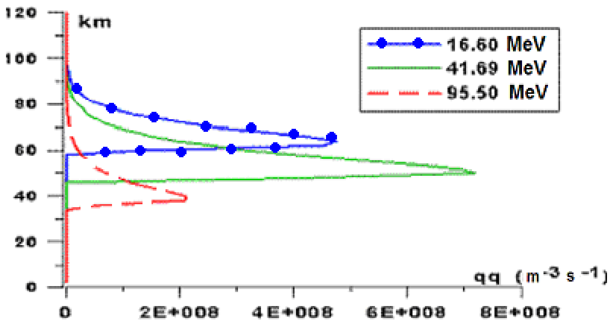

Figure 1. The ionization of the Earth's atmosphere rate by solar protons of different energies calculated for SPE 2000.07.17 (70 degrees of the north latitude)

3. CORONAS-F experiment

Information about proton fluxes was based on the measurements from the boards of GOES-10 and CORONAS-F satellites. CORONAS-F was launched into a circular orbit with an inclination of ~82.5o and with an initial altitude of about 500 km on July 31, 2001. It operated until December 12, 2005 with a final altitude of about 350 km. Its orbital period of 94.8 minutes corresponds to about 15 circuits per day.

The SONG instruments based on large (∅ 20 cm, h=10 cm) CsI(Tl) crystal detected X-ray and gamma-emission in a wide energy range 0.03-200 MeV [Kuznetsov et al., 2004].

Charged particles in different energy ranges (protons with energy: 1-90 MeV, electrons: 0.3-12 MeV) were measured by semiconductor and plastic scintillator telescopes [Kuznetsov et al., 2002]. Due to the low polar orbit of the satellite fluxes of solar protons and electrons were measured by the MKL-device onboard CORONAS-F experiment only in the south and north polar caps (areas of open magnetic field lines) during 15-20 minute intervals every ~45 minutes. Therefore it should be noticed that solar protons data (1-5, 14-26, 26- 50 and 50-90 MeV) were obtained on board CORONAS-F satellite at altitude near 400 km.

4. Solar emission observed during the second half of January, 2005

Despite of that fact, that 2005 year is far enough from the solar activity maximum of the current cycle, four flares of X-class (GOES classification) were observed during the active area NOAA 0720 moving trough the disk of the Sun in January, 2005 (January 15, 17, 19 and 20). All of them were detected by SONG instrument on board CORONAS-F satellite which measured X- and gamma-rays with the energy from 0.03 up to 200 MeV (see Table 1). In the flare 20.01.2005 maximal energy of gamma-rays detected by SONG, has exceeded 100 MeV. The measured shape of gamma-ray spectra demonstrated that the gamma-emission was formed as a result of neutral π-meson decay. All detected flares were powerful enough and have led to the appearance of powerful fluxes of solar particles.

Table 1. Major solar flares observed during the second half of January, 2005.

Data, dd/mm/yy	UT, start- max. SXR, (GOES)	UT, start – end (CORONAS-F)	Class/ ball	Coordinates of flare
15/01/05	22:25- 23:02	22:59- 23:03	X2.6/-	N15W05
17/01/05	06:59- 09:52	ERB-10:00	X3.8/-	N15W25
19/01/05	08:03-08:22	08:10- ERB	X1.0/-	N15W51
20/01/05	06:36- 07:01	06:44- 07:00	X7.1/2B	N14W61

These events that have took place near to the minimum of solar activity, represent considerable interest, and any experimental information on them is valuable from the point of view of forecasting of solar flares during the periods of a minimum and decay of solar activity.

The time profiles of solar protons low energies measured on board three satellites - ACE situated in L1 point (1.06-4.75 MeV, green line), GOES-10 operated on the geostationary orbit, (0.9-4 MeV, violet one) and CORONAS-F which had the polar circular orbit, so the solar proton flux was measured in polar caps at altitudes near 400 km (1-5 MeV, red one) from 16 to 19 January 2005 measured are presented in figure 2 (top panel). On the bottom panel of the figure 2 the results of the Earth's atmosphere ionization rate according to GOES-10 data are shown.

One can see that all three main peaks of ionization rate at highest (85-95 km) altitudes (marked by black lines) caused by proton peaks, which were measured by GOES-10 but were observed neither ACE nor CORONAS-F satellites in the similar energy channels. The ACE and CORONAS-F data are in a good agreement.

We have the reasons to conclude that these three marked enhancements detected by GOES-10 were not the solar particles but magnetospheric ones (GOES-10 have detected the particle flux enhancements were it crossed the tail of Earth's magnetosphere). So, one should not to use the low energy proton channels GOES-10 data for the Earth's atmosphere ionization rate calculations. In figure 3 the time profiles of solar protons with the energies in the wide range from 1 to 90 MeV measured by CORONAS-F (1-5, 14-26 and 50-90 MeV), ACE (1.06- 4.75 MeV) and GOES-10 (40-80 MeV) are shown (top panel). On the bottom panel of the figure 3 the results of the Earth's atmosphere ionization rate calculations according to CORONAS-F data are presented.

We can see that the result of the Earth's atmosphere ionization rate calculations according to CORONAS-F solar protons data looks more adequate than ones according to GOES-10. The enhancements of solar protons with energies 1-5 MeV have led to high ionization rate at rather high altitudes – 85-110 km (maximum – near 90 km), marked by the black lines. Especially clear such influence of low energy solar protons January, 21 after CME coming to the Earth's orbit.

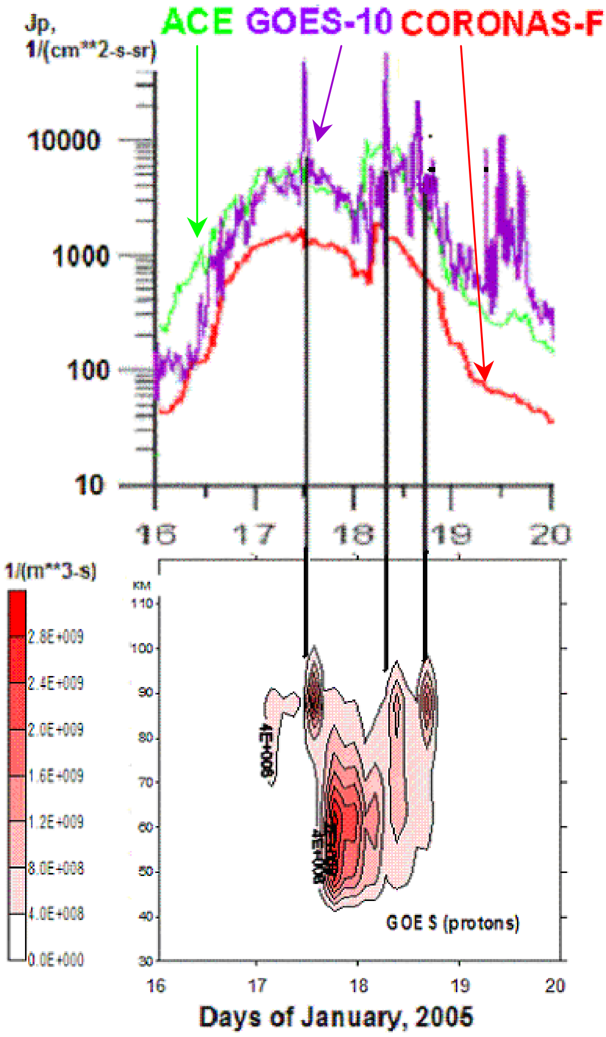

Figure 2. Solar proton flux variations observed by ACE, GOES-10 and CORONAS-F satellites during 14-19 January 2005 time period and calculated ionization rate according to GOES-10 data.

High ionization rate at lower altitudes (40-60 km) are caused by the enhancements of solar protons with higher energies (more than 50 MeV) marked in figure 3 by red dashed lines. Such behavior of ionization rate dynamics is in a good agreement with the calculations results presented in figure 1. We should notice (see figure 3) that solar proton flux in the energy interval 40-80 MeV measured by GOES-10 and one in the energy interval 50-90 MeV measured by CORONAS-F in the polar caps are in the very good agreement. So GOES data cannot be used for the Earth's atmosphere ionization rate calculations only for the protons with low (less than 10 MeV) energy.

5. NO_2, OH and ozone variations in the Earth's atmosphere – the results of modelling.

In figures 4, 5 and 6 the results of calculations of NO_2, NO and OH variations in the Earth's atmosphere (in the northern hemisphere, higher than 70 degrees of the northern latitude) during SEPs of January 2005 are presented.

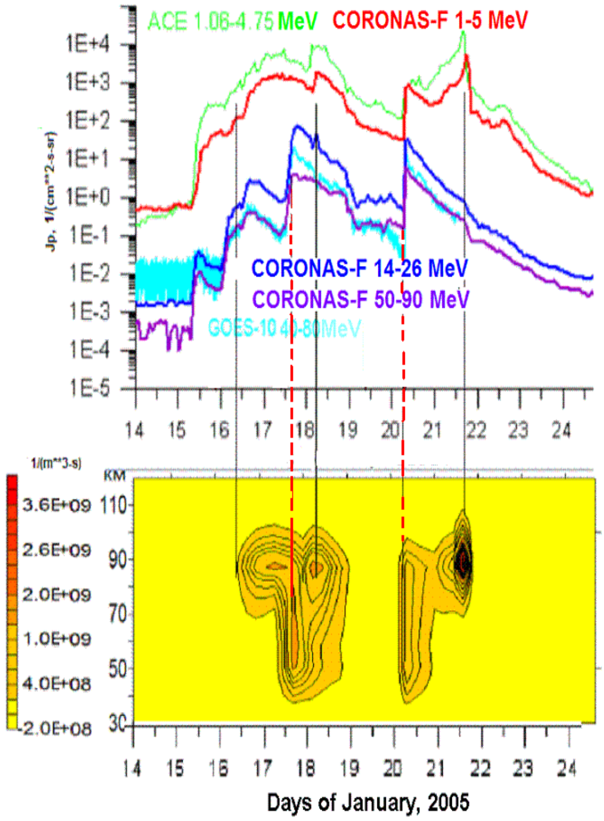

Figure 3. Solar proton flux variations observed by CORONAS-F, ACE and GOES-10 satellites during the second half of January 2005 and caused by the results of the Earth's atmosphere ionization rate calculation according to CORONAS-F data.

The figures 4-6 shows that the maximum of NO_2, NO and OH variation should be observed during the 17-18 January, after the powerful SEP 17 January caused by solar flare X3.8 (see Table 1). The calculations show that the altitude of this maximum should be observed near 70-80 km.

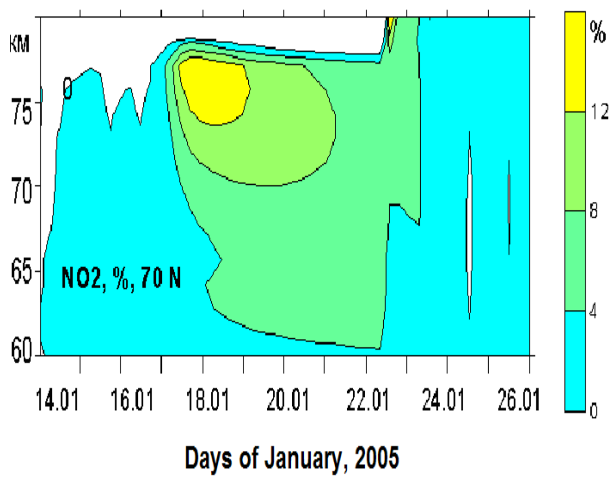

Figure 4. NO_2 variations in the Earth's atmosphere (in the northern hemisphere) from 14 to 25 January 2005

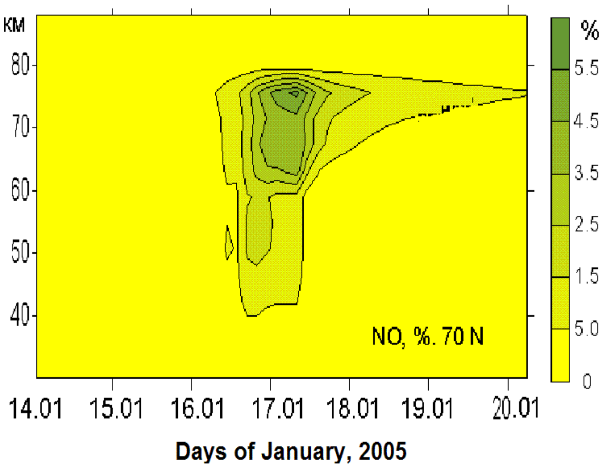

Figure 5. NO variations in the Earth's atmosphere (in the northern hemisphere) from 14 to 19 January 2005

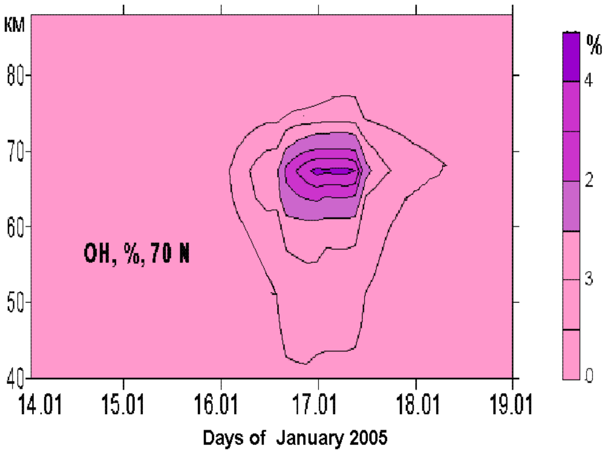

Figure 6. OH variations in the Earth's atmosphere (in the northern hemisphere) from 14 to 18 January 2005

The ozone variations in the Earth's atmosphere during ten das from 15 to 25 January 2005 are presented in figure 7.

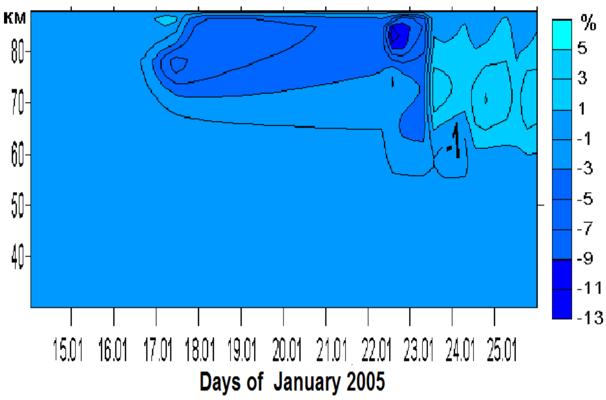

Figure 7. The response of ozone layer at 70^0 N after SPEs of January 2005

From figure 7 one can see that the first maximum of ozone variations should be observed after the powerful SEP 17 January caused by the solar flare X3.8 at altitude about 75 km (like NO_2, NO and OH variations). But the second maximum at higher altitudes (80-82 km) should be observed later, 22 January – after the enhancement of solar protons with the low energy (1-5 MeV) connected with the CME, which reached the orbit of the Earth in the late evening of 21 January.

6. Conclusion

Presented results confirmed that significant ozone destruction can be caused by SPE-produced NOx and HOx amounts (such mechanism was introduced in photochemical model). Another aspects related to cosmic ray influence on the atmosphere also exist [Krivolutsky, 2003].

It was shown that solar proton events of January, 2005 have strongly influenced a condition of high-altitude atmosphere of the Earth. The obtained results of the modeling based on the polar low-altitude satellite CORONAS-F data (which was during the considered period at altitude about 400 km) are significantly differ in comparing with ones based on the data of geostationary satellite GOES-10. It is probably caused by difference of observable fluxes and spectra of protons (in particular with 1-5 MeV energy) at the geostationary orbit and at low (400-500 km) altitudes due to their different nature – pure solar or mixture of solar and magnetospheric ones.

So, ozone layer of the Earth is under simultaneous forcing of solar energetic particles, which partly destroys it mostly during solar proton events. Such SPE-induced ozone depletion may changes temperature regime (due to the changes in ozone heating), and winds in the atmosphere, determining cosmic weather in ozone layer of the Earth.

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