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THE INFLUENCE OF COSMIC RAYS ON OZONE ABOVE 20 KM BY MICROWAVES OBSERVATION

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Abstract. This paper deals with the influence of protons and neutrons flows on ozone content in the stratosphere measured by microwave radiometry methode at two stations (N.Novgorod and Apatity). It is shown that solar bursts can cause reduction of ozone level at altitudes 50-60 km. The correlation coefficient between ozone density at altitudes 25, 40, 60 km and cosmic rays data (numbers of protons from satellite GOES-8 and numbers of neutrons measured by land stations). The altitude averaged correlation coefficient between ozone and neutron data increases from the negative to positive value while the altitude steps up from 25 to 60 km. In the one event this increase of correlation coefficient lies within the range from negative significant value (-(0.4 – 0.6)) to around zero, in another event – within the range from around zero to positive significant value (0.2-0.6). The correlation coefficient between ozone and solar cosmic rays data obtain a statistically significant value during solar activity period.

Introduction

The clearing out of the reasons of stratospheric ozone variability is an important atmosphere physics problem, since ozone layer is a screen, which protects the Earth biosphere from solar ultraviolet radiation. At present it is well known that significant fluctuations of ozone contents at altitudes above 20 km could be caused by the dynamics of atmosphere in particular by stratospheric warming and internal gravitational waves [1, 2]. There is one more possible ozone variations type, which was caused by nitric oxide formation due to cosmic rays (CR) influence. Studying these variations is important for the following reasons. First, it can show that stratospheric ozone content depends on the rate of the known molecules NO_X transformation. Second, these variations allow one to understand the reason of the assumed 11-year cycle of the total ozone contents. Thirdly, these variations are connected with some hypothetical mechanism of long change terrestrial climate, caused by stratosphere.

There are two types of cosmic ray. The first type is galactic cosmic rays (GCR), which change the electric atmosphere characteristics at altitudes of 5-30 km. The other type of CR is solar cosmic rays (SCR). SCR can be accompanied by solar protons bursts, which exist relatively seldom, but they can cause significant atmosphere ionization at altitudes over 30 km. The primary large energy particles influence on the atmosphere consists in ionization. After the forming of primary ions, some ion-molecular reactions run, which form ozone-active compounds. SCR are registered mainly at solar activity period, and their maximum phase does not concur with the maximum GCR, which maximum accounts for minimum solar activity. Besides, the energy of SCR is less in contrast with GCR, so they penetrate only in higher stratosphere layers. In papers [3, 4] is shown that entering of very intensive solar protons can influence the stratospheric ozone. The analysis of modern studies state in the field of observations and model estimations of CR influence on ozone at the middle atmosphere is considered in review [5]. Some recent papers have instructions on possible effect of ozone contents reduction after proton phenomena in the Sun [6, 7]. However, there is practically no information about how background CR variations influence upon the stratospheric ozone.

In this paper long microwave observations O_3 at altitudes more than 20 km in arctic and temperate latitudes were used for estimation of possible CR influence on the stratospheric ozone. Microwave observations allow one to carry out permanent monitoring with high spatial and temporary resolution of ozone content variations in the middle atmosphere. Besides proton events we use the information about CR neutron component. CR consists at the ground level basically of protons and neutrons, which are registered by the sensors of land stations. Recent studies have showed there is a correlation between the number of neutrons variations, registered in a layer atmosphere and intensity of ozone spectral lines, which belonged to the radio wavelengths band [8].

Comparison of observational results

Microwave observations data in Apatity (67N, 35E.), Kola Peninsula and Nizhny Novgorod (56N, 44E) during 1998 – 2003, usually in winter [9] were used for analysis. To retrieve ozone vertical profiles from the measured spectra, we have used the model-fitting method. As retrieval procedure, model vertical distributions of pressure and temperature were used. Spectra, averaged for day ozone, were used for analysis. The estimation error of vertical distribution ozone at altitudes of 20-60 km was less than 10%. Considered were neutron monitors data in Apatity (http://pgi.kolasc.net.ru/cosmicRay) and in Troitsk (near Moscow, http://cr0.izmiran.rssi.ru/mosc/main.htm), and protons data from geostationary satellite GOES-8 (http://spidr.ngdc.noaa.gov/spidr/index.html) were used for comparison with ozone density variations. The normalized correlation coefficient for the daily averaged ozone and CR rows was used as value, estimated the quantity of CR influence on ozone contents. (For rows of neutrons or protons correlation coefficient is marked further K_N and K_P, accordingly.)

We consider ozone density row only for heights h = 25, 40, 60 km, as typical and deferring for its behavior at period cosmic and atmospheric phenomena. Examples of ozone density rows at heights 25, 40 and 60 km were shown in Fig. 1-2. Those rows were obtained by microwave measured at Apatity and at N.Novgorod.
Moreover for illustration from all obtained data were chosen mostly full rows for winter 2002/2003 (at Apatity) and 1998/1999 and 2000/2001 (N. Novgorod). It's should be underlined that winter 2000/2001 include mostly active solar protons events; microwave observations were almost simultaneous at two stations. In Fig. 1-2 on two lower panels are displayed also the numbers of protons (the threshold 10 and 100 MeV) and numbers of neutrons.

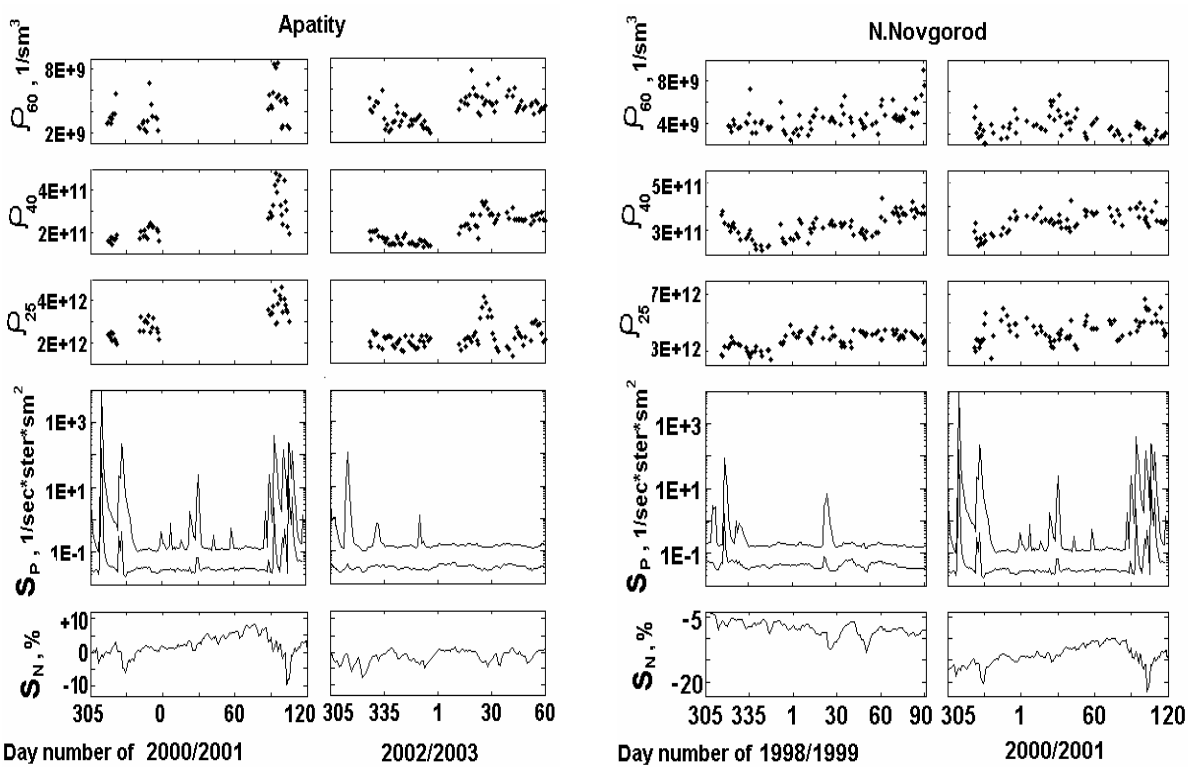

Fig. 1 Fig. 2

Fig 1-2. Graphics of comprised data. Axes X- day number of corresponding years. From to bottom: ozone densities ρ_{60}, ρ_{40}, ρ_{25} at altitudes 60, 40 и 25 km accordingly, proton flux density S_P measured by satellite GOES-8, lowest graphic – neutron number S_N , measured land neutron monitor at Apatity or at Troitsk (for N.Novgorod ozone data).

Discussion and conclusion

Data processing results are represented in Table 1. For each period 95%-confidence interval and threshold value in parenthesis are shown (if correlation coefficient exceeds this threshold it is considered as statistically significant with probability 95%). Below K_P and K_N estimations are located. Additional index beside K_P indicates energy threshold in MEV, if the energy of the proton exceeds this threshold, these proton is taken into account. Only 10 and 100 MeV thresholds are considered (they are mostly essential). Threshold of 100 MeV corresponds to the lower curve for protons (at Fig.1-2). Four periods of microwave measurements at Apatity and at N.Novgorod are considered, including simultaneous (left and ruling table parts accordingly). Periods without simultaneous microwave measurements are placed in the lowest part of the tables (at the fourth row). Values of K_P and K_N for short (approximately two weeks) observations interval when the series of strong solar bursts were occurred are shown in the third table row.

Below, calculations results are considered in detail. Firstly, we deal with the relationship between ozone density and neutron number. One can easily see that at 25 km K_N are either not significant or significant negatively, at 60 km - either not significant or significant positively, and at 40 km both not significant and significant values are present. Thus, the correlations averaged at fixed altitude, coefficient sign changes from negative to positive while altitude increase varies from 25 to 60 km. There is an accordance between our conclusion and results of other authors. The paper [10] noted the relationship between CR and ozone content in the troposphere, the author said that K_N is positive in the troposphere, but at altitudes of 20-25 km the sign of K_N must be changed. The result of modeling, presented in [11], shows that ozone response to GCR variations is negative at 25 km and positive at 40-60 km and below 20 km, moreover, the value of response at 40 km is less than the absolute value of ozone response at 25 km.

Now we will turn to protons influence on ozone layer. Note that percentage events number in Table of significant K_P approximately twice as little, than percentage events number of statistically significant K_N. Events, when K_P exceeds the threshold of statistical significance can be divided into two groups. One of them includes the period a winter 2002/2003. It's can be noticed that correlation coefficient between the neutrons and high-energy protons (statistically significant K_P correspond only them) for the period 2002/2003 is around 0,8. This statement means the K_{P100} and K_N values describe the same relationship between ozone and CR. Thus we can see close importance K_{P100} and K_N values in the corresponding table parts.

Three short periods of observations when K_P obtains significant values included in the second group. These fragments are the November-December of 2000 in Apatity (in the second table row when microwave observations do not corresponded to solar proton events of November 9, 24-26, see Fig.1), and the period presented in the third table row (which illustrates the relationship between ozone and cosmic rays at the period of mostly intensive solar event at April of 2001). Last fragment is characterized by several closely situated strongly solar bursts. In particular the density of proton flow with energy more than 100 MeV increased approximately in 100 times at April 3, in 10 times at April 10 and in 50 times at April 12 in contrast with background period. During this period significant ozone density fluctuation on altitudes more than 40 km at Apatity (see Fig.1) are taken place, but at N.Novgorod ozone variability was essential below (see Fig. 2). Ozone content at Apatity at layer 50-60 km at followed days after the bursts at the March 29 and at the April 3,12 averagely decreased by (42.8±21.4) %. Although K_P and K_N take relatively high magnitude, but number of points for analysis is small therefore evaluation precession of correlation coefficient is low and there is doubt about significance of K_P and K_N. Surprise can be appeared by positive importance K_P value while contents ozone decreases by response to solar bursts. Moreover the ozone and protons row are strongly broken at considered interval. So using correlation coefficient for estimation of CR influence on ozone in this case can be biased.

	Apatity			**N. Novgorod**		
	23.01.00-29.03.00		**±0.05 (0.29)**	**11.01.00-31.03.00**		**±0.05 (0.32)**
***h*,km**	**25**	**40**	**60**	**25**	**40**	**60**
K_N	-0.44	-0.39	- 0.09	- 0.40	- 0.55	0.04
K_{P10}	0.16	0.09	0.02	0.16	0.07	- 0.14
K_{P100}	- 0.00	- 0.01	- 0.1	0.02	- 0.11	- 0.11
	15.11.00-27.12.00		**±0.10 (0.43)**	**22.11.00-27.04.01**		**±0.03 (0.23)**
***h*,km**	**25**	**40**	**60**	**25**	**40**	**60**
K_N	0.01	0.17	0.31	- 0.07	0.44	0.18
K_{P10}	- 0.47	- 0.57	- 0.04	0.09	0.05	-0.1
K_{P100}	- 0.06	- 0.49	- 0.18	0.16	0.18	- 0.15
	28.03.01-14.04.01		**±0.12 (0.47)**	**29.03.01-13.04.01**		**±0.23 (0.63)**
***h*,km**	**25**	**40**	**60**	**25**	**40**	**60**
K_N	0.03	0.40	0.43	- 0.57	0.82	0.72
K_{P10}	- 0.43	0.51	0.46	- 0.05	0.24	0.35
K_{P100}	- 0.40	0.43	0.39	0.03	0.18	0.24
	22.11.02-6.03.03		**±0.03 (0.23)**	**11.11.98-31.03.99**		**±0.03 (0.22)**
***h*,km**	**25**	**40**	**60**	**25**	**40**	**60**
K_N	0.2	0.52	0.34	- 0.43	- 0.13	- 0.01
K_{P10}	0.03	-0.11	0.02	- 0.12	0.00	- 0.09
K_{P100}	-0.13	0.45	0.52	- 0.07	0.00	- 0.1

We can formulate a few conclusions now. AS follows from microwave observations at polar and middle latitude during 23[rd] solar cycle, there were, after proton events, a short time (about a day) decreasing of ozone content (~ 40%) at the heights 0f 50-60 km. The ozone variations are good correlated with the proton flux fluctuations just at the time of enhanced solar activity (it is clearly visible at the Polar Regions). However, the correlation coefficient between averaged (on a day scale) values of ozone density (the levels of 25, 40 and 60 km) and mean proton fluxes is, basically, statistically insignificant.

As to the neutron component of CR, it is changing its sign of correlation coefficient with the ozone variations depending on the height of ozone layer (it was discussed above). We would like to point out also that the CR influence on ozone layer can, sometimes, compensate each other (excluding, probably, the case of Forbush-effect). The atmospheric dynamics also can change the state of ozone layer thus smoothing the cosmic rays influence. We had, for instance, an experience of filtering of stratospheric warming effect, it allowed to increase both K_P and K_N.

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