Reaction of the total ozone content to the Forbush decrease of the galactic cosmic ray flux

V.I. Demin, V.V. Pchelkin, and M.I. Beloglazov

Polar Geophysical Institute,
Kola Scientific Center of the Russian Academy of Sciences, Apatity, Murmansk Region

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Our study revealed that investigating the reaction of the ozonosphere to the change of the galactic cosmic ray flux requires the air synoptic situation to be accounted for or researchers must pay attention to the consideration of a great number of events. Based on the statistical analysis of more than 200 cases of the Forbush decrease (separately strong and weak) no significant response was revealed of the total ozone content at eight stations located in northern latitudes.

Introduction

The change of chemical composition of the Earth's atmosphere at the cost of modulation of the galactic cosmic ray flux (GCRF) is frequently considered as one of possible mechanisms of the effect of solar activity on the weather and climate processes (see, for example, Refs. 1 and 2). It is assumed that the change of vertical ionization profile produces the corresponding reaction in the concentrations of trace gases of the atmosphere including ozone. Because ozone plays a decisive role in the atmospheric radiation balance, the change of its concentration should inevitably result in the variation of thermobaric fields in the stratosphere that finally will affect the character of circulation in the lower troposphere.

The most efficient proof of the reality of such a mechanism could be an immediate experimental detection of the reaction of the total ozone content (TOC) to the variations of GCRF. Reference 3 describes the 10–15% increase of the TOC at six stations of the European territory of Russia during a period of the Forbush decrease (FD) of GCRF on February 15, 1978. At the same time Ref. 4 describes the TOC decrease during FD periods. Statistical increase of the number of events up to 21 for one point and the use of some data on the dynamics of altitude baric fields in the literature[5] suggested the possibility that the total ozone content keeps constant during FD period. Thus different concepts of solving the above problem have been described in the literature. Taking into account the fact that the hypothesis on the influence of solar activity on weather phenomena by changing TOC is used as before to explain a series of meteorological and climatic effects (see, e.g., Ref. 6), the study of this problem is still of practical interest.

Methodical grounds

Unfortunately, the majority of examples of TOC response to the Forbush decrease, given in the literature, including separate very memorable events, do not describe the aerosynoptic situation, while it is well known that even the change of air mass over the observation point is capable of producing TOC change by 5 to 30%, including several hours long periods during which the axis of the jet stream (JS) passes over.[7–10]

Thus the variations of TOC during FD period described in Ref. 3 were observed at the stations located in the action area of two planetary high-altitude frontal zones and corresponding jet streams, and the period from 10 to 22 February of 1978 according to the catalog of types of synoptic processes of the northern hemisphere, given in Ref. 11, fell within 3 elementary synoptic processes: from February 10 to 13, from February 14 to 16, and from February 17 to 22. Therefore the 10–15% increase of TOC revealed by the authors of Ref. 3, could be caused by a simple change of air mass with different ozone content.

A conservative estimate should be made for the report on the TOC reaction to the Forbush decrease at high latitudes during winter period at the east phase of a quasi-biennial cycle, Ref. 12, both because of very small sampling (that is emphasized by the authors) and because the daily variations of TOC in the arctic air mass during winter period, when its central and peripheral parts are located under different conditions of illumination, have a large amplitude due to wave processes.[7] According to the climatic data,[13] the arctic high-altitude planetary frontal zone (and related jet stream) is situated practically at auroral latitudes; in some cases the northern branch in planetary frontal zone of mid-latitudes can penetrate to this area. In this situation, at temporal agreement of passing of the axis of jet stream and the Forbush decrease, the TOC variation, due to only dynamic causes, can be interpreted, sometimes erroneously, as a response of the ozonosphere to the change in cosmic ray flux.

It is also important that 30% change of TOC at the intersection of the jet stream axis, evidently,

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exceeds the above changes of TOC under the effect of changes in GCR flux. By this we mean that when superimposing a given dynamic process and the change of TOC, due to the Forbush decrease, the effect may even have different signs, and the obtained contradictory results are caused by this effect when considering the specific events.

Talking into account the above data it is evident that for detecting a real response of TOC to the Forbush decrease, it is necessary to have either an obligatory consideration of aerosynoptic situation and a check of the circulation homogeneity for each of those several cases, which were considered by the authors of Refs. 3, 4, and 12, or a great increase of the number of the events being considered is needed for smoothing out the variations due to the dynamic processes in the atmosphere. Below the results are given of the analysis carried out using the second method.

Applicable database

In this paper the number of Forbush decreases, included in the analysis, was significantly increased: more than two hundred of events were used that is much larger than in the above-mentioned papers.[3–5,12] Another idea, realized in the present research, was an assumption that the situation could develop in different ways for the Forbush decrease of different types. An effort was made to reveal this difference.

It is known from the history of magnitospheric studies that for a long time the phenomenon of intensity decrease of GCR was observed only by the ground-based detectors and was related to magnetic storms. In this case the Forbush decrease was determined as the GCR intensity decrease during magnetic storms.[14] The qualitative and quantitative widening of the experimental database (and, first of all, the spaceborne observations) resulted in an understanding that the Forbush decrease is mainly a modulation effect caused by the interaction of GCR with large-scale inhomogeneities of solar wind.[15] These inhomogeneities, in their turn, correspond to the sources of plasma fluxes of different classes: solar flares, coronal cavities, disappearing filaments, belt coronal rays[16]; and this can result in differences in FD. Taken alone, the idea is apparent, for example, the flare FDs, in particular, are accompanied by the X-ray flare, and the recurrent FDs are not accompanied by it. The list of similar differences can be continued. The nature of FD can be judged from the complex of observation data – both at the Earth's surface and in the outer space.

In recent years a simple and reliable criterion of identification of flare and other FDs has been developed (first of all, determined by disappearing filaments) based on simple analysis of FD amplitudes. In Ref. 15 it is stated that practically all Forbush decreases with the amplitude exceeding three percent are flares, and the decreases due to, e.g., suddenly disappearing filaments have the amplitude less than 1.5 percent. Using this criterion, we considered the flare FDs separately.

The database is used in the paper, created specially for investigating FDs and the corresponding correlation dependences, and containing results of ground-based observations (neutron monitors) of cosmic rays as well as spaceborne measurements of solar wind and MSP parameters.

Data on TOC were taken from the reference books "Total ozone content and spectral transmittance of the atmosphere. Reference data on USSR stations" (1972–1989). Data on TOC TOMS spaceborne measurements were also used (http:/toms.gsfc.nasa.gov.). When investigating the relation between TOC and GCR flux characteristics the superposed-epoch method was used. In this case the analysis was made separately for strong ($A_F > 2.3\%$) (about 60) and weak ($A_F < 1.5\%$) FDs.

Analysis of the results

Because the TOC response to the variations of the cosmic ray flux can be expected at high latitudes, we have chosen for analysis data from the observatories of Murmansk ($\varphi = 68.97°$N, $\lambda = 33.05°$E), Dikson ($\varphi = 73.50°$N, $\lambda = 80.23°$E, Olenek ($\varphi = 68.50°$N, $\lambda = 112.43°$E), Tiksi ($\varphi = 71.58°$N, $\lambda = 128.92°$E), Igarka ($\varphi = 67.47°$N, $\lambda = 86.57°$E), Markovo ($\varphi = 64.68°$N, $\lambda = 170.42°$E), Arkhangelsk ($\varphi = 64.58°$N, $\lambda = 40.50°$E), Pechora ($\varphi = 65.12°$N, $\lambda = 57.10°$E).

The variations of TOC during 10 days before and during 11 days after strong FDs, obtained by the superposed-epoch method, for the above listed observatories are shown in Fig. 1. Because of errors in some observations of TOC, the number of events included in analysis for different observatories appeared to be different.

As stated above, the TOC variations at a change of air masses amount to as much as 30%. Therefore, relatively small sample does not allow natural variations to be smoothed out. However, Fig. 1 shows that as the number of events considered increases the variations become less pronounced (ideally, the variation of TOC up to "zero" day obtained with the use of the superposed-epoch method should be a straight line). At the same time, the character of TOC variations up to "zero" day caused only by dynamic processes in the atmosphere and after the beginning of FD practically does not change. Moreover, assuming that TOC does not change in the processes of FD, a straight line was drawn parallel to x-coordinate axis, reflecting the mean ozone content over this observatory during all days when the events were studied and 5% deviations from it are shown by the vertical bars. It should be noted that practically all the variations of TOC before and after the beginning of FD are found to be less than 5%; and in this case the increase of the number of events only confirms this conclusion.

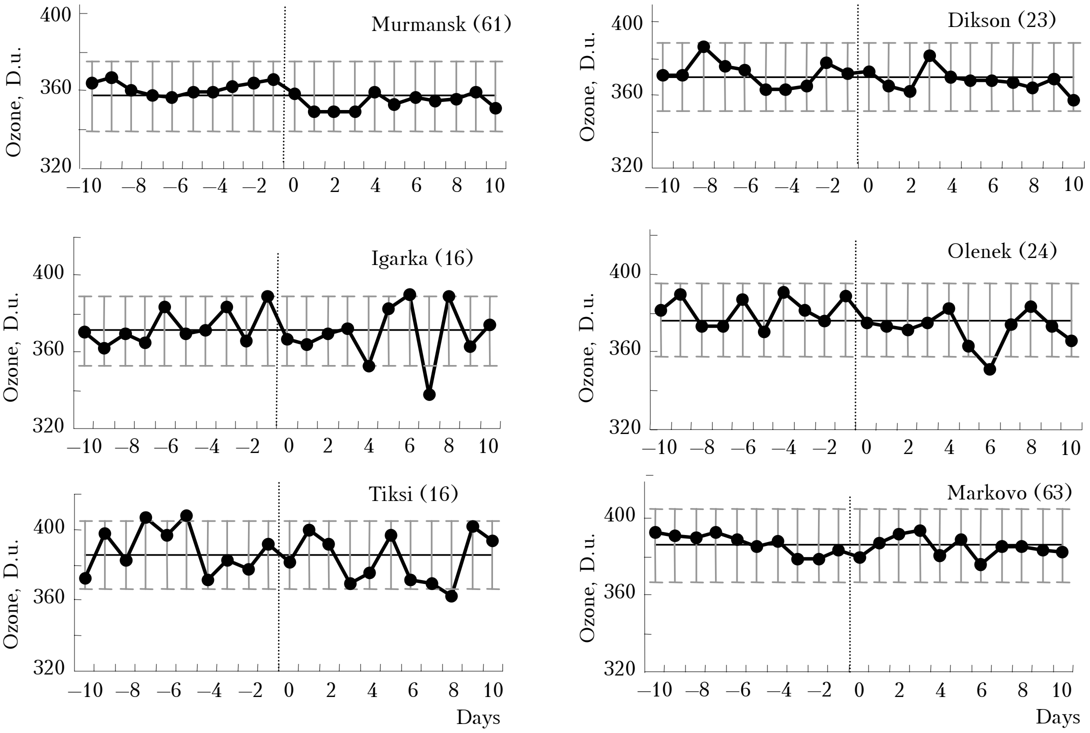

Fig. 1. Variations of TOC during 10 days before and during 11 days after strong ($A_F > 2.3\%$) Forbush decreases of GCR (the number of events considered at a given station are shown in brackets).

Invoking weak FD to the consideration ($A_F < 1.5\%$) does not change the pattern. Figure 2 shows the variation of TOC over Murmansk during 10 days before and 11 days after weak FD, obtained by the superposed-epoch method for 150 events. The TOC variations, in this case, do not exceed 5% deviation from the mean value over the period under study.

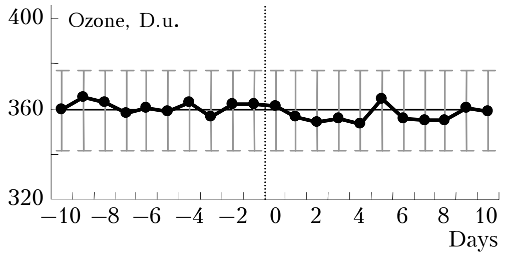

Fig. 2. Variations of TOC over Murmansk during 10 days before and 11 days after weak ($A_F < 1.5\%$) Forbush decreases of GCR (150 events).

Similar result can be obtained when using another method of analysis. It is known[17] that the greatest differences in the ozone content of different air masses are observed in February–April when, e.g., the difference between the values of TOC in the arctic and mid-latitude air masses is, on the average, 80 to 100 D.u. (between the arctic and tropical air masses it is more than 100 D.u.); in this case the least difference is observed in August–September only 15–20 D.u. Accordingly, the effect of the change of air masses will be the largest in the end of winter and in spring, and the least one in the end of summer, beginning of fall (Fig. 3).

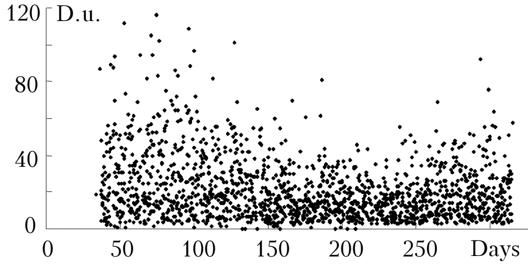

Fig. 3. Daily variations of TOC (modulus) over Murmansk in 1998–2003.

In this connection, an attempt to detect a response of TOC to FD has been very promising at the period when its variations due to dynamic processes of the atmosphere are minimal and, respectively, the effects from the change of the cosmic ray flux could be more pronounced.

For this purpose we have chosen 27 strong FDs that occurred in August–September over a period from 1972 to 2001, and using the superposed-epoch method, we considered the changes of TOC over Murmansk, Arkhangelsk, Pechora, and Markovo. The results are shown in Fig. 4, from which it follows that in this case no special TOC variations after the beginning of FD, as compared with the variations up to "zero" day, occurred: the changes in TOC with an amplitude no more than 5 D.u. (or 1.5%) are observed.

The presence of the negative trend over Murmansk, Arkhangelsk, and Pechora is caused by the annual variation, when the decreases of the mean long-term TOC values during 30 days period in August–September are 15 D.u. On the contrary, over Markovo, in the given period, TOC practically did not change (in July – 332 D.u., in August – 323 D.u., in September – 326 D.u., in October – 335 D.u.) and this also manifests itself in the corresponding absence of the trend in data shown in Fig. 4.

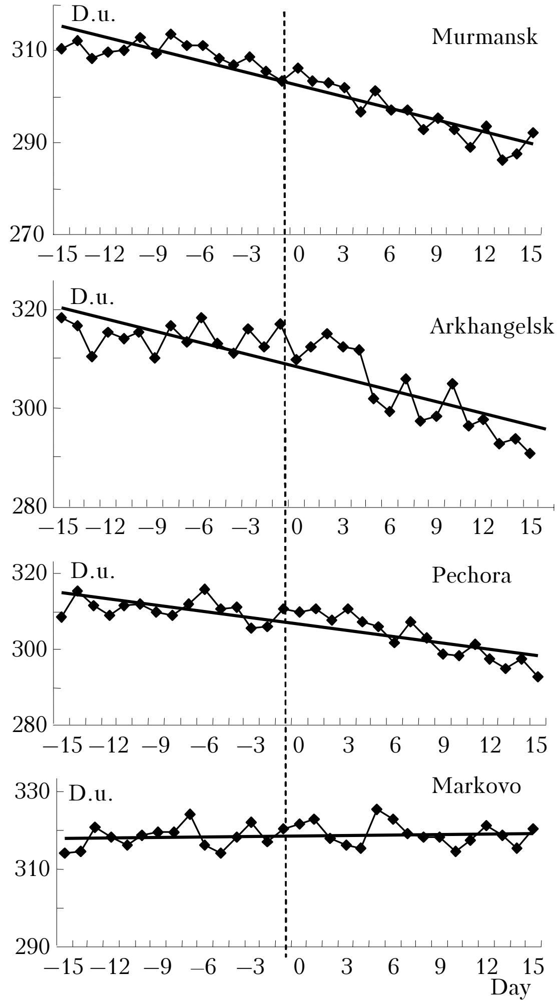

Fig. 4. Variations of TOC for 27 strong Forbush decreases of GCR in August–September over a period from 1972 to 2001.

Conclusion

Thus the results of the analysis made using a very significant statistical material (8 high-latitude observatories and more than 200 events) allow us to draw the conclusion that no changes in the total ozone content occur during the Forbush decreases of GCR (or they do not exceed natural fluctuations being below 1–2%).

Acknowledgments

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