BARIC SYSTEM DYNAMICS DURING FORBUSH DECREASES OF GALACTIC COSMIC RAYS

I.V. Artamonova\(^1\), S.V. Veretenenko\(^2\)

\(^1\) Institute of Physics, St.Petersburg State University, St.Petersburg, 198504, Russia, e-mail: artamonova@hotbox.ru; \(^2\) Ioffe Physico-Technical Institute of the Russian Academy of Sciences, St.Petersburg, 194021, Russia

Abstract. Short-time effects of galactic cosmic ray (GCR) variations on the baric system evolution at middle latitudes of the North Atlantic were investigated. A noticeable pressure growth after the sharp GCR intensity decreases (Forbush-decreases) was found, the maximum of pressure being observed over Scandinavia and the northern region of the European part of Russia on the 4th day after the event beginning. It was shown that the detected pressure growth was caused by more intensive anticyclone development in the region of climatic Arctic front. It was suggested that the particles which precipitate in the regions of the Arctic (\(E \sim 20-80\) MeV) and Polar (\(E \sim 2-3\) GeV) fronts may influence the processes of cyclone and anticyclone formation in frontal regions.

Introduction

The variations of the cosmic ray flux are now considered as one of most important agents linking solar activity and the lower atmosphere. The studies of solar activity influence on the formation and evolution of extratropical cyclones are of significant importance, because the weather conditions at middle latitudes strongly depend on the cyclones forming over the North Atlantic and the North Pacific oceans. In particular, Veretenenko and Thejll (2004) showed that precipitations of high-energy solar protons into the Earth’s atmosphere resulted in the increase of cyclone activity near Greenland. Tinsley and Deen (1991) found a decrease of vortex area index (VAI), i.e., a weakening of cyclogenesis during Forbush decreases of galactic cosmic rays (GCR), mainly at the latitudes \(\sim 40-65^\circ\)N over oceans. Pudovkin et al. (1997) also showed that according to the data of aerological soundings in Sodankylä (Finland, \(\varphi \approx 67^\circ\)N), Forbush decreases were accompanied by an increase of pressure, with the maximum being observed on the +3/+4 day after the event onset. These results were in good agreement with zonal pressure variations in the latitudinal belt 50-75\(^\circ\)N according to Pudovkin and Babushkina (1992). Veretenenko and Artamonova (2005) revealed that the pressure increase over Scandinavia and the northern region of the European part of Russia during Forbush decreases of GCR took place due to more intensive formation of blocking anticyclones in this region.

In this work we continue studying the baric system dynamics during Forbush-decreases of galactic cosmic rays on the base of the extended statistical data and show that the pressure increase areas turn to be in the regions of the climatic position of the main atmospheric fronts.

Experimental data analysis

We analysed daily averaged values of geopotential heights (GPH) of the main isobaric levels 1000, 850, 700, 500, 300 and 200 hPa using NCEP/NCAR “reanalysis” data (Kalnay et al., 1996) to investigate the effects of Forbush-decreases on the variations of pressure in the lower atmosphere.

We selected 48 Forbush decreases during the cold half of the year (October-March) for the period 1980-2006 using the Apatity neutron monitor data (http://pgi.kolasc.net.ru/CosmicRay). The events selected for our study had to satisfy the following criteria:

a) on the first day of the event the decrease of the neutron monitor counting rate exceeded 1% relative to the undisturbed level which was calculated by averaging the data over 5 days before the event onset;

b) the amplitude of the Forbush-decrease exceeded 2.5% relative to the undisturbed level;

c) no intensive solar proton fluxes (i.e. with the intensity \(I > 100\) proton\(\cdot\)cm\(^{-2}\)\(\cdot\)s\(^{-1}\)\(\cdot\)sr\(^{-1}\)) for particles of energy \(E > 10\) MeV had to be observed during the first days of the Forbush-decrease.
The events were selected for the cold period (October-March), because in this half of the year the maximum intensity of cyclonic activity is observed. The superposed epoch analysis was used to calculate the mean pressure deviations from the undisturbed level, which was obtained by averaging the GPH data over 10 days before the event onset. The day of the event onset was considered as the zero day.

The mean variations in geopotential heights of the isobaric surface 1000 hPa during Forbush decreases under consideration are presented in Fig.1. The white lines indicate the areas, where the statistical significance of the deviations is above 0.95 and 0.99 according to the Student $t$-criterion. As it seen from the figure, a slow pressure growth takes place near the south-eastern coasts of Greenland on the first days ($0/+1$ days) after the Forbush decrease onset. Then, the area of the increasing pressure extends in the north-eastern direction and reaches its maximum on the $+3/+4$ days after the Forbush decrease beginning, covering all Scandinavia, the north of European part of Russia and the Arctic Ocean coasts. The deviations from the undisturbed level in this region amount to $\sim 60-70$ gp.m.

Variations in geopotential heights of the isobaric levels 1000, 850, 700, 500, 300 and 200 hPa on the $+4$ day after the Forbush decrease onset, which is the day of the greatest pressure increase, are shown in Fig.2. White lines show the areas where the effects are significant at 0.95 and 0.99 confidence level. Black and blue lines show the climatic position of the Arctic and Polar fronts in January, respectively [Khromov and Petrociants, 1994].

The data in Fig. 2 show also the climatic position of the main atmospheric fronts at middle latitudes in January according to Khromov and Petrociants (1994). Atmospheric fronts are rather narrow transition bands between air masses with different thermal characteristics which are formed over different kinds of surface. The
Arctic front separates in winter the cold Arctic air over Greenland from the warmer air of middle latitudes over the ocean, whereas the Polar front separates the air mass of middle latitudes from the tropical air mass. The main atmospheric fronts are of particular interest for the studies, because the cyclonic activity at extratropical latitudes is closely related to these fronts. Most of extratropical cyclones arise and undergo significant changes in their evolution namely at the Arctic and Polar fronts. Indeed, the most appreciable pressure deviations are observed in the regions of the climatic position of these fronts, i.e. in the areas of intensive cyclogenesis. This allows the suggestion that a possible reason of the observed pressure deviations may be the changes in cyclone and anticyclone evolution.

![Fig. 2](image)

Fig. 2 Mean variations in geopotential heights (in gp.m) of the isobaric levels 1000, 850, 700, 500, 300 and 200 hPa on the +4 day after the Forbush-decrease beginning for 48 events (1980-2006, cold half of year). White lines show the areas where the effects are significant at 0.95 and 0.99 confidence level. Black and blues lines show the climatic position of the Arctic and Polar fronts in January, respectively [Khromov and Petrociants, 1994].

To check this assumption, the weather chart analysis was carried out. The weather charts provide comprehensive information about atmospheric conditions at the moment of observation, in particular, about the spatial distribution of air masses and their characteristics, the atmospheric fronts and the different baric systems such as cyclones and anticyclones, troughs and crests. An example of the synoptic situation on the +3/+4 days of the Forbush decrease which started on the 13 January 1988 is presented in Fig.3.
We can see that on the +3 day (16 January 1988, left panel) the high pressure area (1025 hPa in the center) is formed over the north of Scandinavia at the cold front of the cyclone with the center over Taimyr peninsula. The cold front stretches along the Arctic coast of Eurasia. There is also an occluded cyclone over Greenland, the pressure in its center is 960 hPa. On the next day (right panel) the cold front is displaced to the south, the pressure in the anticyclone reaches 1030 hPa, its area increases noticeably and covers both Scandinavia and the north of the European part of Russia. The cyclone near Greenland does not move and rapidly fills up to 980 hPa. Similar processes were found to occur in most cases.

Thus, the results of synoptic analysis showed that, as a rule, after the Forbush decrease onset the transformation of intensive mobile cold anticyclones into slowly-moving ‘blocking’ anticyclones takes place. These anticyclones create an obstacle for the transport of air masses from the North Atlantic to the continent. This process results in the decrease of intensity as well as in the slowing or even in the stop of cyclones, which usually move to the east (or to the north-east) in the zonal flow. As a result, the pressure over Scandinavia and the north of the European part of Russia starts to growth.

**Fig. 3.** Example of synoptic situation on the +3/+4 days of the GCR Forbush decrease starting on the 13 January 1988.

**Fig. 4.** Mean variations in geopotential heights (in gp.m) of the isobaric level 1000 hPa on the +4 day after the Forbush-decrease beginning, superposed by the geomagnetic cutoff rigidity (R, GV) map, and the climatic position of the main atmospheric fronts at middle latitudes in January [Khromov and Petrocians, 1994].
According to Shea and Smart (1983), the geomagnetic cutoff rigidities in the areas of most intensive anticyclone activity vary from ~0.2 GV to 0.4 GV (the Arctic front region) and from ~2 GV to 3.5 GV (the Polar front region), that corresponds to the energies ~20–80 MeV and ~2–3 GeV, respectively. The geomagnetic cutoff rigidity map and the climatic position of the main atmospheric fronts at middle latitudes in January [Khromov and Petrociants, 1994], are shown in Fig. 4. As it seen from the figure, the main atmospheric fronts under study turn to be in the zones of precipitation of particles with the minimum energy ~20–80 MeV (the Arctic front) and ~2–3 GeV (the Polar front). The intensity of cosmic particles with such energies is strongly modulated by solar activity that allows considering them as the most probable link between solar activity and the lower atmosphere. An intensification of anticyclones in the regions of particle precipitations with the indicated energies seem to provide new evidence that the variations of these particles are involved in the physical mechanism of solar activity effects on the formation and development of extratropical baric systems.

Conclusions

This investigation showed that Forbush decreases of galactic cosmic rays are accompanied by the noticeable pressure growth at middle and high latitudes, the most significant effects were found in the regions of the climatic Arctic front stretching from the Greenland coasts to the Arctic coasts of Eurasia and of the Polar front in the eastern part of the North Atlantic. The result obtained suggest that the pressure changes associated with the events under study are due to the changes in the intensity of cyclonic activity (i.e. formation and development of extratropical cyclones and anticyclones) in these regions.

The synoptic analysis showed that the observed pressure increase in the Arctic front region was really caused by the changes in the evolution of mobile anticyclones forming in the rear of frontal cyclones. It was revealed that after the Forbush-decrease onset these anticyclones transformed very often to so called ‘blocking’ anticyclones slowing their movement over Scandinavia and, thus, creating an obstacle for the movement of North-Atlantic cyclones in the eastern direction. This process contributed to the pressure increase over Scandinavia. The results obtained are in good agreement with the previous studies by Pudovkin et al. (1997) who revealed a growth of pressure in all the troposphere at Sodankylä station (Finland) and with the studies by Tinsley and Deen (1991) who showed a decrease of cyclonic vorticity at middle latitudes associated with Forbush-decreases of GCR.

We suggest that the cosmic particles having sufficient energies to reach geomagnetic latitudes of the Arctic front ($E \approx 20–80$ MeV) and of the Polar front ($E \approx 2–3$ GeV) may take part in the processes of cyclone and anticyclone formation and development in the frontal regions.

References