Forbush-effects and atmospheric pressure dynamics at high-altitude Tien Shan station

V Antonova, S Kryukov
Institute of the Ionosphere of «National Centre for Space Research and Technology», Almaty, Kazakhstan
E-mail: valanta@rambler.ru

Abstract. We present atmospheric pressure dynamics studies at the high-altitude Tien Shan station (3340 m above sea level) during 23rd cycle of solar activity after Forbush-effects. It is established that 80 % of Forbush effects with delay 1 ÷ 3 days are accompanied with steady depression of atmospheric pressure irrespective of geomagnetic field conditions. We found that atmospheric pressure dynamics at mountains and ground levels during investigated periods is different. Experimental results are compared with possible mechanisms of influence of sporadic effects of solar activity on circulation of the lower atmosphere.

1. Introduction
The reality of impact of solar activity sporadic phenomena on atmospheric pressure dynamics is established now by many researchers. However due to various reasons so far the character of the atmospheric pressure response upon this influence is discussed. Ambiguity of the established relations, discrepancy of estimates of the response of atmosphere parameters, difficulties of division of internal and external of disturbance sources led to different ideas of the mechanism of transfer of disturbances from the Sun in the lower atmosphere of Earth. Now deficiency in them isn't present: dynamic, electric, optical (electromagnetic radiation and change of the atmosphere transparency), condensation [1-7]. Statistical relation of the lower atmosphere parameters with geomagnetic storms was received [8-10]. The aim of this work is study of the relation of atmospheric pressure dynamics at the high altitude Tien Shan station (3340 m above sea level) between Forbush-effects (FE), character of the response of atmospheric pressure and its comparison at different heights.

2. Experimental data, results of the study
In this studies we used the experimental data of the interplanetary magnetic field (IMF) magnitudes from the archives of NASA SPDF (Space Physics data facility), the cosmic rays (CR, the neutron component) with account of barometric effect, atmospheric pressure (P) from the database of high altitude Tien Shan station, the geomagnetic field (Institute of the Ionosphere, Almaty, Kazakhstan) during the 23rd cycle of solar activity (1997-2007).

2.1. Forbush effects and solar flare
The main selection criterion of events for the study - Forbush effect ≥ 3%. Such events during the years 1997-2008 was 62. For all events analyzed the state of interplanetary and geomagnetic fields (GMF), variations of the neutron component CR and the atmospheric pressure. It is established that
80% of Forbush effects with delay 1 ÷ 3 days are accompanied with steady depression of the atmospheric pressure irrespective of GMF conditions. Figure 1 demonstrates the results of observations of two events with FE. On the left panel (top-down) we observe the increase magnitudes of IMF, the magnetic storm, the decrease of the CR intensity due to FE (November 1997). The positive correlation is observed between pressure and the CR intensity with the 12 hours delay. The decrease of the pressure during two days was 14 mbar. The right panel of Figure 1 demonstrates the results of observations of geophysical and cosmophysical parameters during October-November 2003. Ground-based neutron monitor network during this period recorded the most significant series of Forbush effects in 23 solar cycles, which includes huge effect on October 29. Geomagnetic observatories recorded a very large geomagnetic storm. The atmospheric pressure at high altitude station decreased more than 10 mbar.

Figure 1. Values of the interplanetary and geomagnetic fields, CR intensity, atmospheric pressure

Solar flare has the opposite effect on the atmospheric pressure. Figure 2 demonstrates two different responses: the increase in pressure following the flare 29.09.1989 and its decrease after FE 20 October.

Figure 2. Values of the CR intensity and dynamics atmospheric pressure after the solar flare and FE

2.2. Geomagnetic storms
Geomagnetic storms and Forbush effects are a consequence of the same disturbance sources of the interplanetary medium. So there is some the ambiguity what the main factor in the mechanism of the
solar activity impact on atmospheric pressure (GM storms or CR). There are many works in which authors substantiates the connection between magnetic storms and changes in atmospheric circulation, the review presented in [3]. However, FE and GM storms not always are recorded by ground level stations after coronal mass ejection (CME) at the same time. FE is determined by conditions in the extended heliospheric region, while geomagnetic activity depends from the local situation near the Earth [11]. Only 53 % FE from our list (62 events) were accompanied by GM storms. We studied atmospheric pressure variations during and after GM storms (K-index ≥ 6) without Forbush effects (12 events). The atmospheric pressure decrease, typical for events with Forbush effect, is not found, figure 3. In the figure the vertical blue lines marks the beginning and the end of the magnetic storms.

![Figure 3. Values of the geomagnetic fields, CR intensity, atmospheric pressure](image)

2.3. Atmospheric pressure dynamics at different heights

Atmospheric pressure at high-altitude station (3340 m above sea level) is much less than pressure at level of Almaty (805 m above sea level), but large-scale variations of pressure are similar. We found that pressure dynamics at mountains and the city levels after FE is different. The results of the neutron component CR measurements in January of 2005 are presented in the upper panel of figure 4.

![Figure 4. Dynamics of atmospheric pressure at different heights](image)

The large FE with a double minimum is observed. The decrease of the pressure at high-altitude station is recorded with delay for 2 days (middle panel of figure 4). In the same panel values of pressure at
level of Almaty are presented. Average pressure at level of high-altitude station and at level of Almaty before (Jan.1-16) and 2 days after (Jan.19-31) of FE are shown by firm horizontal lines. One can see that the average value of the pressure at high-altitude station after of FE is much lower than before. At city level it became a little higher. Pressure values during the same period for 2 stations of Irkutsk (3000 m and 435 m above sea level, http://cgm.iszf.irk.ru/) are presented on the bottom panel of figure 4. It is evident that the average pressure at high-altitude station of Irkutsk with delay ~ 2 days from FE beginning decreased. At the same time at city level (Irkutsk) average pressure increased by 3 mbar. These results are consistent with the results obtained for stations of Almaty.

3. Discussion
We tried to choose one or another mechanism of the impact of solar activity sporadic phenomena on atmospheric pressure, which would be consistent with results of the study. In section 2.2 it was shown that changes of circulation in the lower atmosphere isn't a consequence of geomagnetic storms. The dynamic mechanism isn't effective too. Not all coronal mass ejections that cause FE, are accompanied by powerful flares of the short-wave radiation required for start of the dynamic mechanism. Positive correlation between changes of pressure and data of CR intensity is received also at high altitude station by authors [6]. However the maximum of correlation function was observed two days before the FE and therefore the cause of the phenomenon is electromagnetic radiation of flares. According to the results of observations at Tien Shan station the decrease of atmospheric pressure occurs after FE with delay 0.5÷3 days and is not advancing. Another mechanism proposed for high altitude conditions - condensation [7] is also inconsistent with the results obtained for Tien Shan. Experimental studies demonstrating effective influence of CR on atmospheric processes and the idea of the mechanism of the disturbance transfer were executed in [1-2, 5]. Cosmic rays are the basic agent of impact on the optical properties of the atmosphere (transparency), on a cloudy cover and a global electrical circuit in their studies. The conclusions of these authors made primarily for the latitudes 50 º ÷70 º N and without taking into account the height of stations. Perhaps, the negative correlation between the cosmic rays intensity and atmospheric pressure, obtained by these authors, and the positive correlation in this study due to these causes.

4. Conclusions
Results of studies of atmospheric pressure dynamics at high altitude station showed that the principal link in the mechanism of impact of solar activity on the lower atmosphere is cosmic rays. It is established that 80 % of Forbush effects with delay for 1 ÷ 3 days are accompanied by decrease of atmospheric pressure at the mountain heights of the northern Tien Shan irrespective of the geomagnetic activity conditions. We found that atmospheric pressure dynamics after Forbush effects at the levels ~ 3000 m and below 800 m is radically different. We compared the effects of some of the mechanisms of solar activity sporadic phenomena on atmospheric pressure; none of them are fully consistent with the results.

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