The effect of atmospheric pressure on variations in the particle flux density of extensive air showers according to experimental data from the Tunka-Grande

© S.D. Malakhov,[1] R.D. Monkhoev,[1,2] I.I. Astapov,[3] P.A. Bezyazeekov,[1] E.A. Bonvech,[4] A. Blinov,[5] A.N. Borodin,[5] N.M. Budnev,[1] A.V. Bulan,[4] P.V. Busygin,[1] P.V. Volkov,[6] P.A. Volchugov,[1,4] D.M. Voronin,[7] A.R. Gafarov,[1] A.Yu. Garmash,[2,8] V.M. Grebenyuk,[5,9] O.A. Gress,[1] T.I. Gress,[1] E.O. Gress,[1] A.A. Grinyuk,[5] O.G. Grishin,[1] A.N. Dyachok,[1] V.A. Erofeeva,[1] D.P. Zhurov,[1] A.V. Zagorodnikov,[1] V. Zirakashvili,[10] A.D. Ivanova,[1,11] A.L. Ivanova,[1,2] M.A. Iliushin,[1] I.A. Kabannik,[2] N.N. Kalmykov,[4] V.V. Kindin,[3] S.N. Kiryuhin,[1] V.A. Kozhin,[4] R.P. Kokoulin,[3] K.G. Kompaniets,[3] E.E. Korosteleva,[4] E.A. Kravchenko,[2,8] A.P. Kryukov,[4] L.A. Kuzmichev,[4] A. Chiavassa,[12] M.V. Lavrova,[5] A.A. Lagutin,[6] Yu.E. Lemeshev,[1] B.K. Lubsandorzhiev,[7] N.B. Lubsandorzhiev,[1,4] A. Lukanov,[7] R.R. Mirgazov,[1] E.A. Okuneva,[1,4] E.A. Osipova,[4] A. Pan,[5] A.D. Panov,[4] L.V. Pankov,[1] A.L. Pakhorukov,[1] A.A. Petrukhin,[3] D.A. Podgrudkov,[4] I. Poddubny,[1] E.G. Popova,[4] E.B. Postnikov,[4] V.V. Prosin,[4] A.A. Pushnin,[1] R.I. Raikin,[6] A.V. Razumov,[1,4] G.I. Rubtsov,[7] E.V. Ryabov,[1] A.K. Sagdeeva,[1] V.S. Samoliga,[1,2] I. Satyshev,[5] L.G. Sveshnikova,[4] A.Yu. Sidorenkov,[7] A.A. Silaev,[4] A.A. Silaev (junior),[4] A.V. Skurikhin,[4] A.V. Sokolov,[2,8] V.A. Tabolenko,[1] A.B. Tanaev,[1] M.Yu. Ternovoy,[1] L.G. Tkachev,[5,9] N.A. Ushakov,[7] D.V. Chernov,[4] A. Shaikovsky,[5] I.I. Yashin[3]

[1] Irkutsk State University,
664003 Irkutsk, Russia
[2] Novosibirsk State University,
630090 Novosibirsk, Russia
[3] National Research Nuclear University „MEPhI",
115409 Moscow, Russia
[4] Skobeltsyn Institute of Nuclear Physics, Moscow State University,
119991 Moscow, Russia
[5] Joint Institute for Nuclear Research,
141980 Dubna, Moscow oblast, Russia
[6] Altai State University, 656049 Barnaul, Russia
[7] Institute for Nuclear Research, Russian Academy of Sciences,
117312 Troitsk, Moscow, Russia
[8] Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences,
630090 Novosibirsk, Russia
[9] Dubna State University,
141982 Dubna, Moscow region, Russia
[10] Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of the Russian Academy of Sciences,
108840 Moscow, Russia
[11] Moscow Institute of Physics and Technology (National Research University),
117303 Dolgoprudny, Moscow Region, Russia
[12] Dipartimento di Fisica Generale Universiteta di Torino and INFN,
Torino, Italy
e-mail: malakhov.sd@yandex.ru

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The paper presents the results of a study of the barometric effect at the Tunka-Grande array, which is part of the TAIGA astrophysical complex and is designed to register the charged component of extensive air showers from high and ultrahigh energy cosmic rays.

Keywords: Tunka-Grande, cosmic rays, extensive air showers, barometric coefficient.

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Introduction

The study of primary cosmic rays (PCR) of high and ultrahigh energies is of great interest in terms of understanding the mechanisms and nature of their origin, which is one of the most important tasks of modern astrophysics. Radiation with an energy higher than 1 PeV was detected using only one possible method based on the property of PCR to generate cascades of secondary particles in the Earth's atmosphere — the so-called extensive atmospheric showers (EAS). EAS basically contains the electron-photon, hadron, muon, and neutrino components, and is also a source of Cherenkov radiation, ionization and radio frequency radiation. All of these components, with the exception of neutrinos, can be directly detected by surface systems, and their reconstructed characteristics can be used to determine the properties of PCR. During its evolution EAS components exhibit different variations because of the atmosphere condition. Here, the largest impact is observed from the atmospheric pressure. From an experimental standpoint, the barometric effect manifests itself in the form of a change in the density of the EAS flux, which ultimately leads to an inaccurate assessment of the PCR characteristics [1].

This paper presents the results of a study of the barometric effect using Tunka-Grande system based on experimental data obtained in April 2022.

1. Tunka-Grande experiment

Tunka-Grande [2] is included in TAIGA astrophysical complex (Tunka Advanced Instrument for cosmic rays and Gamma Astronomy) [3], located 50 km away from Baikal lake, and is intended for studying the energy spectrum and PCR mass profile, as well as for studying the diffusive gamma-radiation at an energy level above 10 PeV. The system has been operating since 2016 and consists of a pool of scintillation counters combined into 19 stations on an area of $\sim 0.5\,\mathrm{km}^2$. Each station consists of two parts: surface and underground. The first one includes 12 counters with a total area of $\sim 8\,\mathrm{m}^2$ and registers all charged particles of EAS during observation. The second one contains 8 counters with an area of $\sim 5\,\mathrm{m}^2$, is located under a layer of soil and is designed to isolate the muon component of EAS. In order to study and account for the influence of atmospheric pressure and ambient temperature on the change in the counting rate (the number of detected events per unit of time), meteorological stations are additionally installed in the surface systems of the two stations.

2. Barometric coefficient

Figure 1 shows the graphs of the hourly average values of the counting rate of the surface part of one of Tunka-Grande stations, curves of atmospheric pressure and ambient temperature versus time. Experimental data were collected in April 2022. The anti-correlation of the station's counting rate and pressure is clearly visible, which proves the presence of barometric effect. At the same time, the effect of air temperature on the counting rate variations is minimized. It should be noted that this behavior is typical for all stations of the system.

Figure 2 shows the hourly average values of the station's counting rate versus atmospheric pressure according to similar experimental data that was used to calculate the barometric coefficient [4]:

$$\beta = (k/f_0) \cdot 100\%,$$

where f_0 — average counting rate for the period of observations, k — offset ratio of the approximation function

$$f(P) = k \cdot P + b.$$

After analysis of experimental data we obtained the value $k = -0.0595 \pm 0.0002$ Hz/mm Hg and $f_0 = 10.1 \pm 0.032$ Hz. Thus, the barometric coefficient was $\beta \approx -0.589$ %/mm Hg.

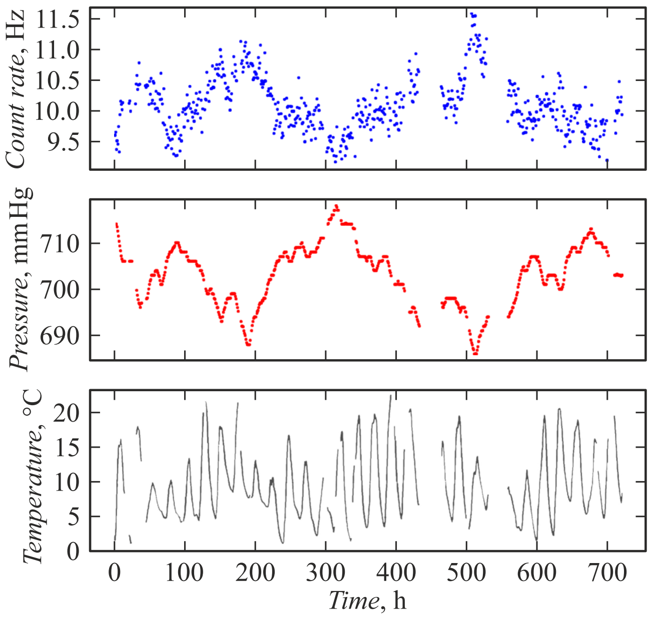

Figure 1. Curves of the station's counting rate, atmospheric pressure and environmental temperature versus time.

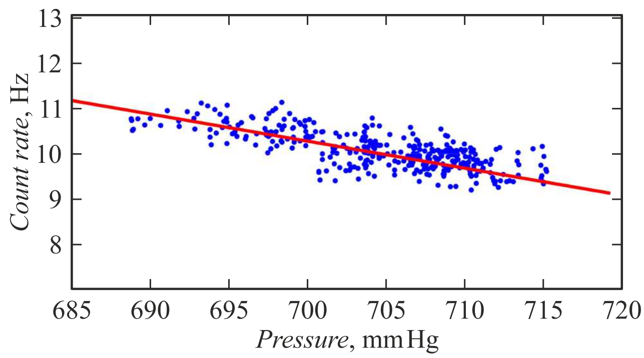

Figure 2. Station's counting rate versus atmospheric pressure. Red line — linear approximation.

3. Prospects of accounting for the barometric coefficient during reconstruction of EAS and PCR parameters

To determine the energy of PCR according to the Tunka-Grande system, the following expression is used [2]:

$$\log(E/eV) = \log(\rho_{200}/(particle \cdot m^{-2})) \cdot 0.84 + 15.99,$$

where ρ_{200} — density of the reconstructed number of particles at a distance of 200 from EAS axis.

In order to increase the accuracy of PCR energy measurements, it is necessary to take into account the influence of atmospheric pressure on EAS power and, accordingly, the error in determining the parameter ρ_{200}. To do this, it is necessary to specify the values of the barometric coefficient, including those depending on the number of operated stations. Currently, experimental data collected over 7 measurement seasons ($\sim 12\,500$ h) is available for analysis.

Conclusion

According to experimental data from Tunka-Grande system, the presence of a barometric effect associated with the process of EAS evolution has been confirmed. It is shown that the barometric coefficient for the individual system stations is 0.589 %/mm Hg. In the future, it is expected to allow for the atmospheric pressure impact during processing and analysis of experimental data, which will improve the accuracy of reconstructing the parameters of SAE and PCR.

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Conflict of interest

The authors declare that they have no conflict of interest.

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