Ionizing particle fluxes in the near-ground atmosphere

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Abstract: Nowadays, a role of ionizing particles in the atmospheric processes is widely discussed. Especially important for the weather and climate formation are the processes in the troposphere, in particular, at altitude below 5 km. Measurements of charged particle fluxes at different levels of the atmosphere are performed by the Lebedev Physical Institute at the polar and middle latitudes since 1957. There are also results of X-ray flux measurements in the atmosphere. Several latitude surveys were fulfilled. At altitudes above 3 km the results of observations are successfully reproduced by the Monte-Carlo simulations of cosmic ray propagation through the atmosphere. At the near-ground levels the calculations predict lower fluxes. To some extent, it may be explained by a contribution of natural radioactivity in the charged particle flux and by cosmic ray albedo due to transition effect between the air and an underlying surface. This work based on the results of observations tries to separate contributions of cosmic rays and radioactivity in the near-ground atmosphere.

Keywords: Cosmic rays, radioactivity, near-ground atmosphere

1 Introduction

Galactic cosmic rays (GCRs) impinge upon the Earth’s atmosphere and create the cascades of secondary particles while interacting with the air nuclei. Geomagnetic field and the atmosphere are the energy analyzers of particles: higher energy is required to access the lower latitudes as well as primary particles of higher energy provide the particle fluxes at lower layers of the atmosphere. Time series of charged particle fluxes at altitudes above $\approx 20$ km (residual atmospheric pressure $P=55$ g/cm$^2$) correlate very well with the GCRs arriving at the same latitude (correlation coefficient $r \approx 0.98$), but this correlation decreases with increase of $P$. At altitudes below $\approx 3$ km $r \leq 0.2$. That means influence of atmospheric factors and natural radioactivity on the ionization in the lower atmosphere. In this work, we use the data of the long-term observations of ionizing particle fluxes in the atmosphere undertaken by the Lebedev Physical Institute, Russia, (LPI) from IGY (1957) to now at several latitudes [1]. Monte-Carlo simulations of particle fluxes fulfilled by L. Desorgher [2], and V.S. Makhmutov [3] reproduce fairly well the observed values at altitudes between 4 and 22 km, but predict significantly lower fluxes in the near-ground level [4]. It is rather expected since calculations do not take into account a soil radioactivity available in the near-ground air layer. However, the discrepancy is also kept in the data of Antarctic measurements where the radioactivity should be depressed by the ice cover. The aim of this work is to analyze the observational data available and to attempt to separate contributions of secondary cosmic rays and radioactivity. We focus on the atmospheric depth more than 700 g/cm$^2$ (altitude $< \approx 3$ km).

2 Observations

The LPI group uses the radiosondes with particle detectors which are carefully preflight calibrated during the whole period of observations. Features of the detectors are given in Table 1.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Protons</th>
<th>Electrons</th>
<th>X-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geiger tube</td>
<td>5</td>
<td>0.2</td>
<td>0.02-0.5</td>
</tr>
<tr>
<td>Telescope of 2 tubes</td>
<td>30</td>
<td>5</td>
<td>none</td>
</tr>
<tr>
<td>NaI(Tl) scintillator</td>
<td>8.75</td>
<td>0.8</td>
<td>0.02</td>
</tr>
</tbody>
</table>

All detectors record charged particles including muons with efficiency of about 100%. Geiger counter is sensitive to X-rays but with efficiency <1%. Telescope is not sensitive to X-rays at all.

The standard radiosonde contains a telescope of two Geiger tubes with a 0.05 g·cm$^{-2}$ steel walls and a 2 g·cm$^{-2}$ thick Aluminum filter inserted between the counters. Count rates of both an omnidirectional counter and a telescope are recorded throughout the atmosphere and transmitted to the ground-level receiver. This work employs the data of following observations:
(1) several times a week balloon launching at Murmansk (geomagnetic cutoff $R_h=0.6$ GV), Moscow ($R_h=2.4$ GV) during 1957-2010, and Mirny (Antarctica, $R_h=0.03$ GV) during 1963-2009;

(2) sea survey with the same devices undertaken in 1987 [5];

(3) X-ray measurements with scintillation counters in 1965-1969 at several latitudes [6];

(4) high precision measurements with a balloon-borne instrument B1 consisting of 240 Geiger tubes of the same type supplemented with scintillation counters (high-latitude Arkhangelsk and mid-latitude Saratov regions) [7].

It should be emphasized that the data of telescopes are free from the radioactivity contribution and that radioactivity is low over the oceans and in the Antarctic.

3 Ionizing radiation in the near-ground atmosphere

Figure 1 demonstrates the results of observations of the particle flux as measured by a LPI omnidirectional counter in 1976 and simulations [2, 3]. Here we focus on disagreement between the calculated and observed values at atmospheric depth more than 700 g/cm$^2$. It should be noted that some inconsistency between the simulated results [2] and [3] is available which probably may be due to different primary GCR spectra used. However, the [3] fluxes should be higher than those of [2] because the former refer to minimum and the latter to the maximum of solar activity. It is really the case for high altitudes, but at $P > 700$ g/cm$^2$ the situation is opposite. Nevertheless, both sets of simulation show the decline relative to observations. On the other hand, it is clear from Fig. 1 that the observational data taken at Moscow region in 1976 (min of solar activity) and in 1990 (max of solar activity) coincide for $P > 700$ g/cm$^2$ within the error bars for the yearly averaged data. Thus, in order to get better accuracy, thereafter we average the observational data over the whole period of observation, i.e. more than 50 years for the Murmansk and Moscow regions and 48 years for Mirny (in total, more than 83,000 balloon launchings).

The results of measurements of omnidirectional radiation at $P > 700$ g/cm$^2$ are summarized in the upper panel of Fig. 2. The results of the sea survey are averaged over all latitudes of the northern and southern hemispheres since no latitude effect was found at $P > 700$ g/cm$^2$. More than 300 launchings from a ship were treated. In spite of not high accuracy a trend toward lower particle fluxes is seen comparing with observations over land. Natural Earth’s radioactivity should lead to particle flux enhancement in the near-ground level. However, the data of the permanent observations at Murmansk, Moscow and Mirny show somewhat retarded decrease but no clear enhancement down to $P \approx 950$ g/cm$^2$. Statistics is not sufficient at lower altitudes. Such enhancements are seen in the data of B1 at

\[ P > 950 \text{ g/cm}^2 \] 

due to contribution of the ground radioactivity [7].

Lower panel of Fig. 2 presents the results of X-ray measurements. The X-ray fluxes at Murmansk and Moscow regions do not differ at $P > 700$ g/cm$^2$ and are averaged in Fig. 2 (lower panel). Data taken over Antarctica (Mirny) prove that radioactivity is low. Both upper and lower panels argue that the radioactivity at $P > 950$ g/cm$^2$ depends on the site of measurements and varies with time. It confirms the results [8].

Consideration of the telescope data (Fig. 3, upper panel) shows that the results at various sites of measurements coincide with each other within the error bars and do not contradict the value obtained at the ground with account of barometric effect [7]. Ratio of count rates of an omnidirectional counter and a telescope $k$ depends on particle composition and their angular distribution. These ratios are calculated for each month and then averaged over time. This procedure gives more precise $k$ than if the ratio would be taken for averaged data of omnidirectional counters and telescopes. The $k$ behaviour at $P > 400$ g/cm$^2$ is expected to depend on $P$ weakly because the cosmic ray initiated cascades are just absorbed in this part of the atmosphere and energy spectra are equilibrium. Value of $k$ increases at $P > 750$ g/cm$^2$ being indicative of existence of some additional particle flux with properties other than those of cosmic rays. However, $k$ of Murmansk and Moscow are consistent down to 900 g/cm$^2$ while the Mirny $k$ is slightly lower. At $P > 900$ g/cm$^2$ the $k$ values are different for Murmansk, Moscow, and Mirny. This is due to the ground radioactivity which depends on the site and is lower at Mirny. In the $P$ range between 600 - 750 g/cm$^2$, where only small contribution of radioactivity is expected, $k$ is almost constant (see lower panel of Fig. 3) and may

![Figure 1: Average fluxes of charged particles in the atmosphere: observational and simulated results.](image-url)
be extrapolated to larger $P$ values as shown by the dotted line. Knowing $k(P)$, it is possible to get the omnidirectional particle flux using the data of telescopes. This flux may represent the omnidirectional particle flux due to cosmic rays in the lower atmosphere. The result is shown on the upper panel of Fig. 2 by the grey circles alongside with the similar result from [7] (grey solid curve). Note that the both sets are in excellent agreement.

### 4 Discussion and conclusion

Upper panel of Fig. 4 demonstrates the observed omnidirectional fluxes (averaged over Murmansk, Moscow, Mirny results and Arkhangelsk results down to $P = 1010$ g/cm$^2$), the expected from cosmic rays flux (obtained from telescope data) and the results of simulation [2, 3]. It is clear that the measured fluxes are higher than both the expected from cosmic rays and simulated fluxes. Displayed on the middle panel of Fig. 4 are differences between the observed fluxes and the GEANT 4 results (symbols and line 1) and the observed fluxes and expected from cosmic rays (symbols and lines 2, 3). Bottom panel of Fig. 4 presents the result of subtraction of X-ray fluxes in the Antarctic (where low if any radioactivity is expected) from the values of X-ray fluxes measured by B1 [7]. The X-ray fluxes behave similar to charged particles at $P > 750$ g/cm$^2$ (curves 4 and 5), but ratios of X-ray fluxes to charged particle fluxes $R_{xc}$ are different. Between 400 and 600 g/cm$^2$ i.e. for GCR secondaries, $R_{xc}$ decreases from 9.5 to 8.8; it is almost constant for populations presented by curves 2 and 4 in Fig. 4 (average $R_{xc} = 3.3 \pm 0.7$), then $R_{xc}$ increases rapidly toward the ground level and reaches values $> 200$, although the latter changes depending on time and site. An excess of the observed fluxes over expected from cosmic rays consists of two populations. That at $P > 950$ g/cm$^2$ (lines 3 and 5) is certainly due to the ground radioactivity, the origin of the excess fluxes between 750 and 950 g/cm$^2$ (lines 2 and 4) is not so clear. Charakhchyan...
et al. [7] ascribed it to the radioactivity of the atmosphere. Now it seems more appropriate to explain it as cosmic ray albedo from the ground due to transition effect between the air and an underlying surface.

Difference between the observed and calculated particle fluxes at $P = 750-950 \text{ g/cm}^2$ is not explained by the ground radioactivity which contributes to lower altitudes. It may refer to the albedo effect since the telescope data also contain albedo particles which we did not account for while calculated expected omnidirectional flux from the data of telescopes. Unfortunately, the present simulations do not consider ionizing particle propagation near/through the air-ground boundary. It is necessary to perform such simulations to reproduce cosmic ray albedo from the underlying surface.

Acknowledgements

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