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On the detailed information in the regular balloon monitoring of cosmic rays: the description of the method and some new results

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Abstract: The method of registration of the detailed information in the experiment of the regular balloon monitoring of cosmic rays in the Earth's atmosphere is described. The use of the detailed information both for improving the results of the experiment and for obtaining further insight into these results as well as the perspectives of the method are discussed.

Introduction

The long-term experiment of the regular balloon monitoring (RBM) of cosmic rays in the Earth's atmosphere has been carried out by Lebedev Physical Institute, RAS, Moscow, Russia, for 50 years (since July 1957), [1], and still provides useful data on both galactic and solar cosmic rays. However there are some flaws in the standard method of data registration that sometimes hinder getting good data, [2]. To overcome some of these shortcomings we suggested recording besides the standard information a so-called detailed information, [3, 4]. Now these data have been recorded for more than 1500 flights.

Here, besides briefly describing the experiment, method and different types of the information, we illustrate how the RBM results can be corrected using the detailed information and also consider some new important features of the data, which could be got only using it. The perspectives of the method are briefly outlined.

The data in the RBM experiment

The principal features of the experiment include: the balloon flying upward and moving with the horizontal winds; the probe suspended to it by strip and oscillating about the vertical; the ground-based receiver-recorder complex; the noise source. The probe includes the baro-detector, two Geiger counter telescope aligned along the strip and the radio-transmitter emitting the pulse each time the ionizing particle passes though the above counter (the shorter pulse) or the telescope (the longer pulse). The receiver picks up both the useful pulses, coming from the RBM probe with the amplitude depending on the distance from the probe to the receiver and the orientation of the transmitter's antenna aligned with the strip, and the noise pulses. The recorder separates the received pulses according to their duration into two groups and counts the number of corresponding pulses for each minute of the flight as a standard information.

One of the flaws of the standard information recorded during the RBM experiment is a finite (one minute) interval of data sampling. It gives no way to reject very short but intense bursts of noise pulses, the fast drifts of the frequencies, turbulence etc., forcing one to discard the whole minute of data. The second, and very important, drawback of standard information is that the separation of the detected radio pulses into two groups is achieved using only one pulse's parameter (its length or duration), neglecting its amplitude and form. It prevents using the information on the amplitude of the useful pulses and also separating the useful pulses from the pulses of the same length due to the noise.

To overcome these flaws we suggested [3, 4] recording a much more comprehensive information coming from the RBM probe. We fed the output voltage from the receiver to the analogue-to-digital converter (ADC) that yielded the value of voltage at regular small intervals (~25 μs). If this value exceeds some small threshold (~160 mV), it is stored into the memory. The continuous set of the stored voltage values is a digital analogue of the pulse. As the length of the useful RBM pulses exceeds 500 µs, the form of each pulse detected by the receiver is described rather well. However up to now we have not registered the amplification coefficient of the receiver, which would allow us to get the pulses incoming to the input of the receiver. That is why we call the above digital pulses recorded during the RBM flight the restricted detailed information (RDI), while by the full-scale detailed information (DI) we mean RDI plus the amplification coefficient.

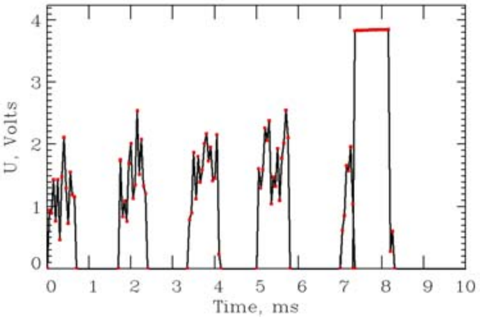

Figure 1:

In Fig. 1 an example of the time sequence of the received pulses using the RDI is shown by the asterisks connected by straight lines. Usually the pulses are far more apart from each other and the period of Fig. 1 is taken from the minute with the highest counting rate of the omnidirectional counter. It is easily seen how the useful pulse (the almost regular rectangle) differs both in its amplitude and form from the noise pulses.

Now we have registered RDI for more than 1500 flights for the last 11 years: 1300 flights in Dolgoprudny (since May 1996) and ~ 200 flights in Apatity (since October 2005). In the next section the advantages of using RDI instead of standard information are illustrated for the easy problems. However, to solve more difficult tasks, demanding separation of the background pulses from the useful ones or the knowledge of the incoming amplitude of the useful pulses (the separation of the background, study of the short-term cosmic ray intensity variations and angular distribution etc), the full-scale detailed information including the amplification coefficient of the radio-detector should be recorded. We have almost all one need to carry out this recording – the radio-receivers; the PCs with multi-channel ADC; the programs for the DI recording with the visualization of the flight.

The analysis of the RDI

In the analysis of RDI we isolate three levels of the data: Level-0 (the initial data) - the set of time T_{ij} and voltage U_{ij}, i=1,..,n_j, j=1,..,K for each of K pulses; Level-1 - the time of the beginning T_j of each pulse, its length L_j and maximum voltage U_j; and Level-2 - the set of P_{ij}, i=1,..,m_j, j=1,..,K for each of K pulses, where P_{ij} is the i-th parameter of the j-th pulse. P_{ij} should be determined approximating $\{T_{ij}, U_{ij}\}$ by some model form of the pulse. To get P_{ij} is rather cumbersome procedure and here we shall discuss only some results of the analysis of the Level-1 of RDI.

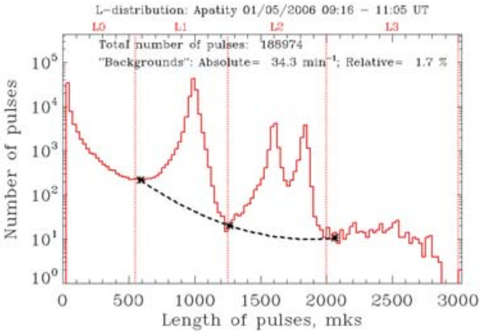

Figure 2:

In Fig. 2 the length distribution of all pulses for an ordinary RBM flight in Apatity (May 1, 2006) is shown as a solid line histogram. The length ranges L0-L3 are shown by the dashed vertical boundaries (those separating L0, L1 and L2 ranges are the standard thresholds for the pulses belonging to the count rates of the omnidirectional counter (L_{01}) and telescope (L_{12}), respectively. So the standard information on the count rates of the cosmic ray detectors consists of the sums

$$N1= \sum_{L>L_{01}} N(L) \qquad (1)$$

$$N2= \sum_{L>L_{12}} N(L) \qquad (2)$$

for the count rates of the omnidirectional counter and telescope, respectively, for each minute of the flight. Note that one can see this length distribution and compare the position of its peaks and valleys with the constant thresholds only using RDI. Before we started registrating it no one has even guessed that there are pulses in the region L3 (the L1 and L2 pulses stuck together), so that strictly speaking summing pulses for N1 the part for L>L23 should be doubled, [3]. Likewise, no one has ever seen how the amplitude of the pulses changes during the oscillation of the probe around the vertical that can be used for the study of the angular distribution of cosmic ray intensity in the atmosphere, [3, 5].

Below we illustrate only some advantages of using the Level-1 of RDI, namely, the possibility to average the number of pulses and their characteristics over an arbitrarily small time interval, e. g., 1 sec. Besides, we shall check the hypothesis that the numbers of pulses in the valleys of Fig.2 give the rough estimate of the number of the noise pulses with the corresponding length. In more exact terms we shall check if the sum of the pulses under the dashed line in Fig.2 divided per period of time of the flight can be consider as noise or background count rate for the RBM experiment (we call it an absolute background). Note that if it is true and if the ratio of this sum to the whole sum (1) (the relative background) is significant it should influence the count rate in the Pfoetzer maximum. The values for both absolute and relative background for the flight considered are indicated in Fig. 2.

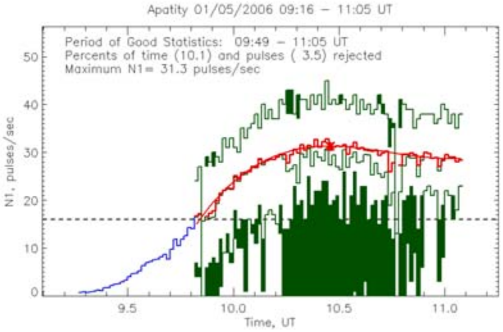

Figure 3:

In Fig. 3 the count rate N1 of the omnidirectional RBM counter is shown for each minute of the same flight as in Fig. 2. Up to a threshold of "good statistics" ($N1_{th}$= $4\sqrt{N1_{th}}$; $N1_{th}$=16 pulse/sec) only one line is drawn (blue), while above it both the average for the whole minute count rate and the upper and lower count rate limits for each second of the minute are shown as thin-line (green) histograms. In the count rate range above the "good statistics" threshold, N1 > $N1_{th}$, where N1 > $4\sigma_N$ (σ_N is a standard deviation of the count rate from its average value $\overline{N1}$) one can use the statistical criteria in full measure. As can be seen in Fig.3 the count rate per second often falls below all values expected from the statistical reasons (the lower limit is often equal to 0). The cause of this effect is not quite understood (see [6]), however it is clear that it does not have a bearing on the time variations of the cosmic ray intensity in the atmosphere. So we rejected the seconds where abs(N1-$\overline{N1}$) > $3\sigma_N$ repeatedly until there were no seconds rejected. Of course, each time (or run) the standard deviation σ_N was calculated anew. The new upper and lower limits of the count rate per second were calculated for each minute and the range between the new and initial limits is filled (green) in Fig. 3 for the minutes where there were seconds rejected. The average for the whole minute new count rate is shown by thicker (red) histogram, then approximated by a third degree polynomial (the smooth red curve). The asterisk shows the corrected count rate N_{max} in the Pfoetzer maximum. One can see that the correction is very significant for this flight, although the percentage of the time and pulses rejected (indicated in the figure) are rather small. Of course, the described procedure of correction should be elaborated to choose the proper number of the runs, the number of standard deviation for rejection in each run, the degree of the fitting polynomial etc. However we believe that the advantage of using even the Level 1 of RDI is evident.

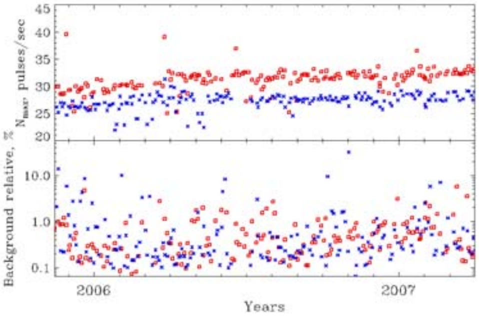

Figure 4:

As the corrected N_{max} and backgrounds are calculated for each flight when RDI was recorded both in Apatity and in Dolgoprudny we can see how they change during about a year and a half (11.2005-03.2007) and if there is any correlation between N_{max} and relative background. In the upper panel of Fig. 4 the count rates in the Pfoetzer maximum are shown for both Apatity (red squares) and Dolgoprudny (blue crosses), while the lower panel shows the behavior of the relative background. It is easily seen that N_{max} changes in rather small limits (probably, the seldom large deviations are due to the extreme length of the counters used not accounted for in the figure). At the same time the relative background varies greatly (by two orders of magnitude) from one flight to another, but these changes do not correlate with those in N_{max}. So our hypothesis that the sum of the pulses under the dashed line in Fig.2 has a bearing to the noise or background count rate is disproved and we should analyze the Level-2 of detailed information to separate the noise pulses.

However, the study of the number of pulses and their characteristics averaged over an arbitrary small time interval, even if useful, is not the best way of using the RBM detailed information. The method adequate to DI should consist of two stages. First task is to discard all noise pulses taking into account the main fact that the characteristics of the useful pulses change regularly from one pulse to another (according to the mean position of the probe with respect to the ground-based complex and its oscillation around the vertical), while the characteristics of the noise pulses do not obey this regularity. To fulfill this task one needs to know the amplitude of the pulses incoming to the receiver, i. e., the fullscale DI. Second stage should use the unique knowledge of the characteristics of each useful pulse (the time of its occurrence, its amplitude and length) to estimate the most probable parameters of both the probe's trajectory and the radiation field in the atmosphere (see [4]).

Conclusions

1. The registration of the full-scale detailed information, the form of each pulse incoming to the radio-detector, during the regular balloon monitoring of cosmic rays, simple and low in cost as it is, allows, in principle, both to improve the accuracy of the main results of the experiment and to fulfill more subtle tasks (separation of the background, study of the short-term cosmic ray intensity variations and angular distribution etc).
2. The detailed information in its present-day reduced version - the form of each pulse at the output of the receiver – easily allows correction of the count rate for the change of the thresholds and for the disappearance of signal.
3. To solve more difficult tasks, demanding separation of the background pulses from the useful ones or the knowledge of the incoming amplitude of the useful pulses, the full-scale detailed information including the amplification coefficient of the receiver should be recorded. We have almost all one needs to carry out this recording – the receivers, the PCs with multi-channel analogue-to-digital converter, the programs.

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