Primary Processing of Multichannel Cosmic Ray Detectors

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Abstract: We analyze the quality of the cosmic ray multichannel detector (neutron monitors, muon telescopes). Different types of instrument variations, their possible causes and methods of their correction are considered. For comparison of similar channels we propose two methods: the median and the method of the ratio logarithms which has clear advantages in comparison with the ordinary method of ratios.

Keywords: multi channel detector, neutron monitor, muon telescope, primary processing.

1 Introduction

Data collecting from modern detectors of cosmic rays (neutron monitors, muonic telescopes) is organized so that to receive the information from each element of the detector (the counter or scintillator), considered as a separate information channel. It allows a conclusion at
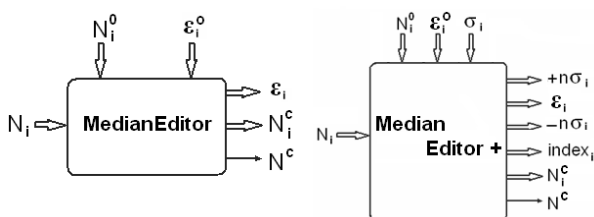

Figure 1. Block-scheme of the Median Editor and Median EditorPlus

primary processing of identical channels about quality of the data of each channel and all detector as a whole. The analysis is reduced to comparison of variations of identical channels for each moment of time. All channels of good order within statistical accuracy should have identical variations. Here there are some questions: concerning what moment of time to calculate variations, what is a method of their comparison, how to do an estimation of statistical accuracy and a trust interval? Some methods are developed for carrying out of such analysis, and as a result the efficiency of each channel and total count rate of the detector are defined. Total count rate of

the detector is simply equal to the sum of all channels if variations of count rate are inside the trust interval – in
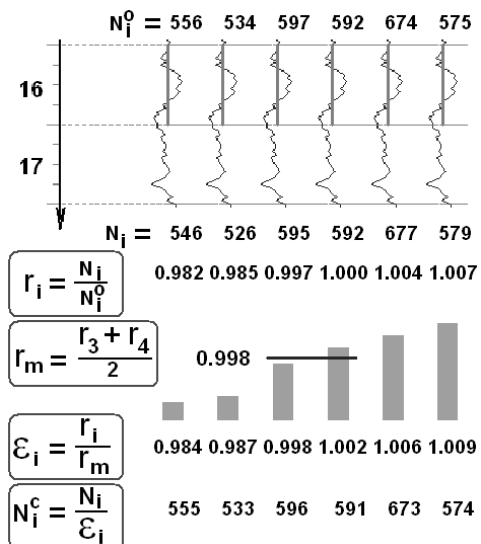

Figure 2. Example Median Editor working

the opposite case the data are exposed to editing. The purpose of such editing is not to restore anomalous channel but to rescue the data of the remained channels. Thus the channel with failure data is irrevocably lost, and there is a question only of how the data of this channel to replace with the most probable values. Only normal channels actually participate in formation of total count rate,

the abnormal channels are used only for normalization of the total counting rate.

What does it mean "efficiency"? If relatively some level N^o at any moment of time the total counting rate has fallen twice, it testifies that efficiency of the detector has also decreased twice and became equal $\varepsilon = 0.5$. To restore level of counting rate it is necessary to execute: $N_i^0 = N_i / \varepsilon$, i.e. efficiency ε is a number, into which it is necessary to divide observable counting rate to get rid of the variations connected with changes of the detector itself. By a definition it may be written for the CR variations: $v = (N_i - N_i^0)/N_i^0 = N_i / N_i^0 - 1$, and taking into account that $N_i / N_i^0 = \varepsilon$, we obtain a connection of the efficiency with apparatus variations: $\varepsilon = 1 + v$.

Tab. 1. Compare of the capability of different Editors.

	1	2	3	4	5	6	ΣN
Input							
N^0	556	534	597	592	674	575	
N_{in}	546	526	595	592	677	579	
SumEditor							
N_{out}	546	526	595	592	677	579	3515
MedianEditor							
N_{out}	555	533	596	591	673	574	3522
ε	0.984	0.987	0.998	1.002	1.006	1.009	
MedianEditorPlus							
N_{out}	546	526	595	592	677	579	3515
ε	0.984	0.987	0.998	1.002	1.006	1.009	
+3σ	1.023	1.026	1.037	1.041	1.045	1.048	
igma	0.945	0.948	0.959	0.963	0.967	0.970	
σ	0.013	0.013	0.013	0.013	0.013	0.013	
SuperEditor							
N_{out}	546	526	595	592	677	579	3515
ε	0.983	0.987	1.001	1.005	1.010	1.013	
+3σ	1.021	1.022	1.021	1.021	1.020	1.021	
-3σ	0.979	0.978	0.979	0.979	0.980	0.979	
σ	0.014	0.014	0.014	0.014	0.013	0.014	

2   Method of median. MedianEditor

In case of normal distribution an average arithmetic and a median coincide in the numerical value. But at small number of measurements both indicators are substantially doubtful, and a median especially. Though the median has also pluses - it less depends on casual estimations. Such property is caused by that in median case the individual values of sharp deviations are emitted, unlike to averaged values. Last property also is used in median editor. The block scheme of the entrance and target channels is resulted on the left panel Fig. 1, and in Fig. 2 example of its work is presented. On an input there are every channel values of counting rate N_i, on an exit -

the efficiency of each channel ε_i, the edited counting rates for each channel N_i^c and of the whole detector N^c. If the reference counting rates N_i^0 and efficiencies ε_i^0 of all channels are known one can find the ratios $r_i = \dfrac{N_i}{\varepsilon_i^0 \cdot N_i^0}$ (in Fig.2, $\varepsilon_i^0 = 1$) and determine median value r_m accounting even-odd numbered channels of detector. Then the values of current efficiencies can be defined as: $\varepsilon_i = r_i / r_m$, and edited counting rates of the channels as: $N_i^c = N_i / \varepsilon_i$. Edited counting rate of the whole detector now is estimated as: $N^c = \sum\limits_{i=1}^{k} N_i^c$. The basic idea of median editor is a pulling up of all channels to median level for the given moment of time. The positive moment is obvious, but there is also some lack: even variations of those channels which differ from median values within statistics range, also are tightened to median level (although not significantly), i.e., strictly speaking, all data is deformed. It shows tab. 1 where possibilities of various editors are compared. Even, if the multichannel detector works well admissible statistical deviations are leveled. In this sense MedianEditor is antipode to simple summation (SumEditor) when the end result joins all channels with their features, except channels with the zero data.

3   Median method. MedianEditorPlus

Distortion of the data is an essential lack of the median editor which is easy for eliminating, applying editing only out of a trust interval. An addition limiting is necessary that if $\left| \varepsilon_i - \varepsilon_i^0 \right| > 3\sigma$, then $N_i^e = N_i / \varepsilon_i$ otherwise $N_i^e = N_i$. But here there is a necessity to estimate value σ for definition of the range of admissible changes of efficiency. Such estimation for the chosen interval can be made, for example, as $\sigma_i = \sigma_i^N / N_i^0 = (N_i^0 \overline{m})^{-1} \sqrt{< N_i^2 > - < N_i >^2}$, where $\overline{m}$ is mean multiplicity of the neutron generation, which is equal ~ 1.41 for the sea level at middle latitudes. The block -scheme of the entrance and target data is presented on the right panel in Fig. 1. In addition an indicator of an exit of efficiency out of limits of a trust interval appears: $index_i$. The problem consists that value σ is necessary to specify constantly as the general counting rate of a detector in due course changes. In case of the data of middle-latitude station σ is approximately equal 0.06 for minute and 0.013 for the hourly data.

4   Method of ratios. SuperEditor

Problem of data processing of the CR is to release of true variations and clean of the data on false (ap-

paratus) variations. However, at the first stage of primary processing it uses to be necessary to search for ways to achieve the opposite situation: to reveal in the pure state apparatus variations, having got rid of variations of the CR. With this aim at comparison of the one-type channels the ratios of their counting rates are used [1,2]. Here we will consider only main principles.

From a definition of the variations of counting rate

Tab. 2. Example of the SuperEditor operating

j \ i	1	2	3	4	5	6
1	1	1.003	1.015	1.018	1.023	1.025
2	0.997	1	1.012	1.015	1.020	1.022
3	0.985	0.988	1	1.003	1.008	1.010
4	0.982	0.985	0.997	1	1.004	1.007
5	0.978	0.981	0.992	0.996	1	1.002
6	0.975	0.978	0.990	0.993	0.998	1
$\varepsilon_i \pm \sigma_i$	0.983 0.014	0.987 0.014	1.001 0.014	1.005 0.014	1.010 0.013	1.013 0.014

$v = (N_i - N_i^0)/N_i^0$ it is follows: $N_i = N_i^0(1 + v)$.

At existing of apparatus variations v_i^D it may be written for counting rate of such a channel: $N_i = N_i^0(1 + v) \cdot (1 + v_i^D)$. If consider the ratios of the channels then is evident:

$$r_{ij} = \frac{N_i}{N_i^0} \cdot \frac{N_j}{N_j^0} = \frac{1 + v_i^D}{1 + v_j^D} = \frac{\varepsilon_i}{1 - v_i^D} = \frac{\varepsilon_i}{\varepsilon_j}$$, i.e. the apparatus

variations are remained and real ones-excluded. For k channel detector it is possible to receive k^2 relations of variations of channels $r_{ij} = \varepsilon_i / \varepsilon_j$. Such nonlinear system of the equations concerning efficiency of channels, having spent its linearization, it is possible to solve ap-

proximately. Really, the expansion of the $1/(1 + v_i^D)$ in terms of Taylor by small parameter v_j (≤ 0.1), leads to already linear diagonal elements: $r_{ij} \approx \varepsilon_i - v_j^D + O(v_j^D)^2$. Summarizing by j gives $< r_{ij} > \approx \varepsilon_i - \frac{1}{n}\sum_{j=1}^{k} v_j^D$ and, neglecting the sum of sign-variable adds, we receive $\varepsilon_i = < r_{ij} >$.

Thus, averaging of the ratios gives efficiency of i channel, and disorder of estimations of the efficiency received according to various channels, gives a rms deviation which defines a trust interval. Block-scheme of the operating of *SuperEditor* is seen in Fig. 3 and presented in Table 2. In the last line of Table 2 the efficiencies of channels are entered and corresponding rms deviations. This is the main idea of the ratio Editor. However, in the Table there is a case when all channels work normal. In reality more complicated task is solving. 1) The analysis of a detector work should be carried out twice for each moment of time.

Figure 3. Block-scheme input - output signals of the SuperEditor.

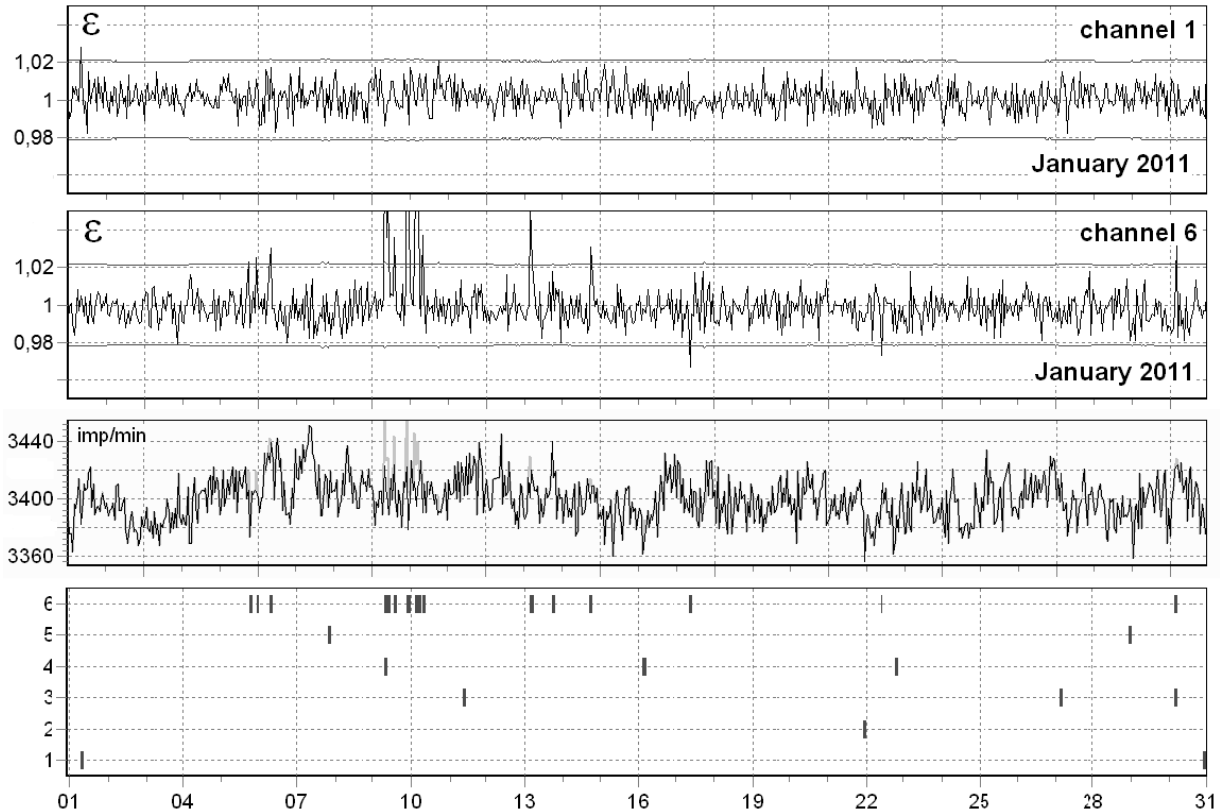At the first stage are divided normal and failure channels.

Figure 4. Sample of data analysis for January 2011

For this purpose consecutively the channels for which the maximum deviation of efficiency from basic value falls outside the theoretically defined corridor, are included in faulty [1,2]; 2) On the next step the efficiencies and trust interval are defined by the correct channels. 3) Method of ratios is connected with nonlinear transformation at the ratios calculation. Under big apparatus variations it makes worse an accuracy of definition of apparatus variation and efficiencies. Instead of ratios we use logarithm of ratio, i. e.,: $\ln r_{ij} = \ln N_i - \ln N_j + \ln N_j^0 - \ln N_i^0 =$

$\ln(1 + \delta_i^D) - \ln(1 + \delta_j^D) = \ln\varepsilon_i - \ln\varepsilon_{jj} \cong \varepsilon_i - \varepsilon_j$,

which under small apparatus variations are equal simply to the efficiency difference. In Fig.3 the block-scheme of input-output data for SuperEditor is presented with the same marks as in Fig.1. In Table 1 a comparison is carried out for various editors on the sample of real data for one moment of time. Output data are the reference counting rate N_i^0 and total count rate of 6-channel detector - N_i. Median Editor correcting data of all channels gives counting rate a little different from simple summarizing. MedianEditorPlus and SuperEditor give equal results. But it is essential that in case of SuperEditor the value σi for formation of trust intervals it is defined automatically, and in case of MedianEditorPlus the values of σi need to be entered from the outside In Fig.4 an example of hourly data analysis by means of SuperEditor for January 2011 from Athens NM is presented. For the channels 1 and 6 the efficiencies and their trust intervals are plotted. On the third panel the indicator of failure channels –they are marked by black squares and are out of trust interval 3σ. в течение месяца можно около 10 значений. On the last panel counting rate of the whole detector after SuperEditor is compared with the values obtained by the simple summarizing

5 Editing of muon telescopes Data

For a muon telescope, with minor amendments, all suitable methods described above to identify the instrumental variations. Number of channels of multichannel muon telescope reaches several hundreds. Strictly speaking, these channels are not all identical, but there are several groups of identical channels. The simplest example of
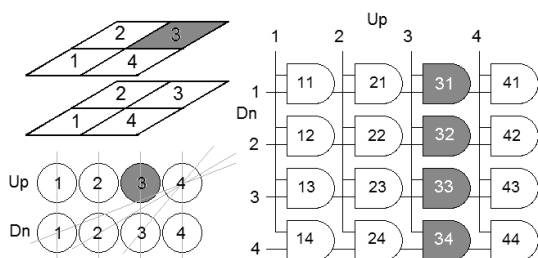

Figure 5. Scintillation (left, top) and counter (left, bottom) telescopes, and the matrix of all the coincidence.

such a telescope consisting of four scintillators in each plane or four counters in each row is shown in Fig. 5.

In the case of a scintillation telescope (Fig. 5) at the output of the system of coincidences you can allocate the following groups of "identical" channels: 4 vertical L0 c11, c22, c33, c44, sloping L1 c12, c43, C41, c32, c34 , C21, c23, c14 and sloping azimuthal L2 c13, c42, c31, c24. Strictly identical channels are the only group L0, channels within other groups differ because of anisotropy of the cosmic rays. Anisotropy can be estimated by the method of crossed telescopes. Themselves of L0-L1-L2 differ due to the zero harmonic, which can also be evaluated according to a telescope. Integrating the data analyzed by each group one of the above editors, you can identify the faulty channel, as shown in Fig. 5. Easily accommodate an insignificant features counter telescope. Variant editor of the tested according to the telescope CUBE [5], consisting of 8 counters in each row.

6 Results and discussion

1) Simple MedianEditor isn't recommended to use for the analysis of data from the CR detectors, as it can't separate normal and faulty channels, and all data tightens to median level

2) As a last resort, it is possible to apply modified MedianEditorPlus, but in this case for formation of a trust interval the estimation of an rms- deviation should be preliminary executed, which depends on variations and needs to be controlled.

3) In all cases of continuous calculation of the efficiencies for separate channels and all detector it is necessary to use SuperEditor which is based on a method of ratios. It can be applied to the analysis of apparatus variations both minute, and the hour data.

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