Median Filtering Algorithms for Multichannel Detectors

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***Abstract*. Particle detectors of worldwide networks are continuously measuring various secondary particle fluxes incident on Earth surface. At the Aragats Space Environmental Center (ASEC), 12 particle detectors with ∼280 measuring channels, each minute are sending via wireless bridges data on count rates of electrons, muons and neutrons. These time series are used for the different tasks of off-line physical analysis and for online forewarning services. Usually long time series contain several types of errors (gaps due to failures of high or low voltage power supply, spurious spikes due to radio interferences, abrupt changes of mean values of several channels or/and slowly trends in mean values due to ageing of electronics components, etc). To avoid erroneous physical inference and false alarms of alerting systems we introduce offline and online filters to purify multiple time-series. In the presented paper we classify possible mistakes in time series and introduce median filtering algorithms for on-line and off-line purification of multiple time-series.**

***Keywords*: Median algorithms, Secondary cosmic rays, Neutron monitor database**

I. INTRODUCTION

Hybrid particle monitors at Aragats Space Environmental Center [1], [2] measure both charged and neutral components of secondary cosmic rays; ASEC data provides good coverage of the violent Solar Energetic Particle (SEP) events of the 23rd cycle. The multivariate correlation techniques applied upon detected fluxes of charged and neutral particles are used for study of geo-effective events, i.e. GLEs, Forbush decreases, Geomagnetic Storms; and for reconstruction of the energy spectra of SCR [3].

The particle monitors are located in the two research stations on the slopes of Aragats Mountain at altitudes 2000 and 3200 meters above sea level and are connected with the data analysis center in Yerevan by means of radio networks. Additionally, there is an ongoing process of establishing a SEVAN world-wide network of detectors operating at different latitudes, longitudes and altitudes [4].

During 23rd solar activity cycle (1997-2008) the old type DAQ electronics used in ASEC had often malfunctioned and there were many errors in the time series.

For the physical analysis we need to purify (correct, filter, smooth) the raw data. Filtering algorithms are usually based on the comparisons of data from identical measuring channels. Particle detectors of the world-wide network of Neutron Monitors [5] usually consist of 3 sections, 6 identical proportional counters in each. If the ratio of count rates of different sections is changing within defined limits the detector overall count rate is performed by simple summon of all sections. If ratio of one of sections is out of limits for both of other sections, the defected section is excluded from summation and the NM overall count rate is properly normalized. The same ideology can be applied for the counters within one section. However, this approach has several disadvantages. It is not fully automated, control parameters should be currently tuned, and algorithm did not correct abrupt jumps [6].

The algorithms based on median filtering are currently widely used in pattern recognition and smoothing in multimedia technologies and scientific applications. For instance, to maximize data output from single-shot astronomical images, the rejection of the cosmic ray background is important. Median algorithms are successfully used for these purposes (see [7]).

This paper consists of the following sections:

- Classification of particle detector failures;
- The description of horizontal median algorithm;
- The description of vertical median algorithm;
- Monitoring of stability of measuring channels.

The advantages of the proposed method are:

1) The algorithms are simple and do not need much computer resources for their realization;
2) They correct abrupt change of means of measuring channels as well as the spurious spikes;
3) Using obtained coefficients described in 3-rd section we can monitor the stability of measuring channels and reveal the even slow drifts of the channel-means;
4) The algorithms can be used not only for offline, but also for online data filtering.

II. TYPES OF PARTICLE DETECTOR FAILURES ENCOUNTER DURING COSMIC RAY FLUX MULTIYEAR MONITORING

Mainly there are 4 kinds of errors and different combinations of these types.

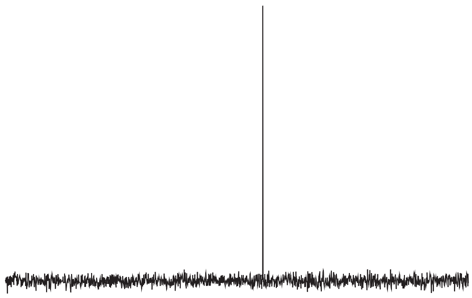

Fig. 1. Abrupt Spike

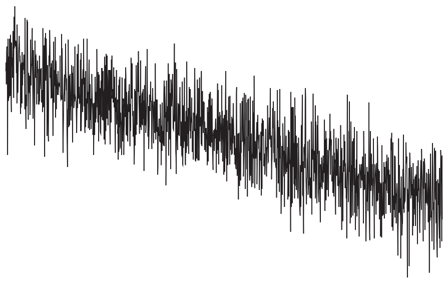

Fig. 2. Slow Drift

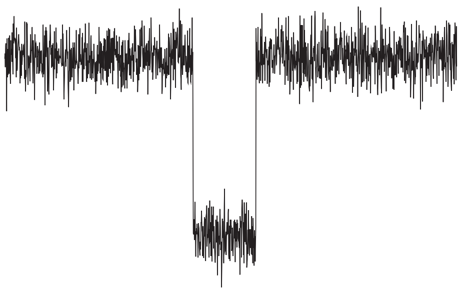

Fig. 3. Abrupt change of mean continued with recovery

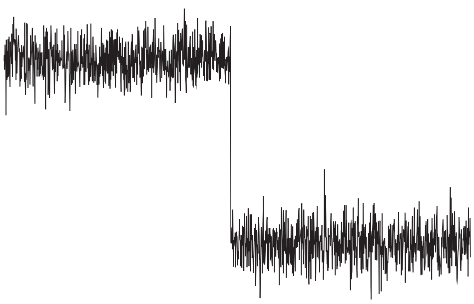

Fig. 4. Abrupt change of mean without recovery

Mentioned errors in particle detectors operation can lead to erroneous estimation of the Fd magnitude; prevent detection of the GLE, (usually not very large at middle latitudes - 1.5-2%), etc. We introduce algorithms based on the stabilizing properties of the median for correction of multichannel detectors data. We heavily use the overabundance of ASEC data due to numerous identical channels measuring one and the same physical quantity (flux of particles of definite type).

III. MOVING MEDIAN FILTER (MMF) HORIZONTAL MEDIAN

Algorithm Description:
Notion:

- Time series of detector channel at moment i is denoted by small letter v_i; median of the L successive elements of time series started at i is denoted by $M_{i,l}$;
- Moving window width L;
- Minimal and Maximal values of the window width L_{min} and L_{max}; $L_{min} < L_{max}$;
- Maximal and minimal possible value of time series median P_{max}, P_{min};
- Maximal possible deviation of time series from median value D_{max}.

Algorithm steps:

1) Select time series from database with N elements;
2) Start algorithm operation from the first of time series, assign i = 0;
3) Define $L = L_{min}$; if $i < N$, then assign i= i+1 and continue;
   otherwise write filtered time series into data base; calculate length of periods when algorithm substitute the time series by the median value, send to operator all messages and stop.
4) Select L-1 elements of time series to the right; calculate the median value $M_{i,l}$; if its value is in the limit of the predetermined values $M_{i,l}$, ε (P_{min} P_{max}) then continue;
   otherwise, check if $L < L_{max}$ enlarge L by 2 and repeat steps 3,4;
   otherwise report about algorithm failure at point i and store algorithm parameters for ith time series: (i, V_i , Lmax); then go to 3;
5) Check if abs(V_i $M_{i,l}$) < Dmax then continue; Otherwise, report erroneous i-th time series, store algorithm parameters (i, V_i, $M_{i,l}$) and assign V_i = $M_{i,l}$ then go to 3.

IV. RELATIONAL MEDIAN FILTER FOR MULTICHANNEL MEASUREMENTS (RMF); VERTICAL MEDIAN

Let's suppose that detector consists of M identical channels, however due to individual characteristics of sensors used (photomultipliers, proportional counters, etc) the mean count rates of channels $\bar{n_i}$, j=1, M are dispersed within definite (not very large) limits.

Notion:

- M number of channels of the monitor;
- $\bar{n_i}$ − mean count rate of j-th channel;
- N$_{total}$ − sum of mean values of all channels (detector mean count rate);
  med$_i$ = med$\{F_i v_i^j\}_{j=1,M}$ Median value of M channels at i-th minute; [1]
- F$_j$ − the equalizing coefficient of j-th channel;
- v$_i^j$ − i-th time series of j-th channel; V$_i$ − estimate of the total detector count rate at moment i.

At the start of detector operation by assigning to each channel the appropriate coefficient F$_j$; j=1, M it is possible to equalize the mean count rates:

$$F_j = (\bar{n_i} M / N_{total})^{-1}; j = 1, M \tag{1}$$

Only after this equalizing operation, it is valid to calculate the median. The detector count rate at moment i can be calculated according to:

$$V_j = M \bullet med_i \tag{2}$$

The median estimate of count rate is much more stable in presence of outliers (bad channels) though its variance is greater comparing with mean value in absence of outliers.
Also if jth channel of detector is continuously and incoherently changing (operating unstable according to reports of MMF) its time series can be substituted by the median value:

$$v_i^j = med_i / F_j \tag{3}$$

The possible scenario of implementation of both algorithms can be as follows:

1) For some initial period of detector operation possibly without any errors the mean count rates $\bar{n_i}$ and coefficients F$_j$ are calculated and stored;
2) At the end of the day the data of all channels of detector are filtered with MMF algorithm;
3) If some channels operate unstable according to reports of the first algorithm RMF turns on, it reads the stored means and coefficients and corrects the malfunctioned channel data;
4) Channel means and appropriate coefficients are renewed and stored;
5) 1.If second algorithm did not correct the data (which means that all or nearly all channels have been corrupted or detector was switched off due to some overall failure) system sends an e-mail to manager.

[1]This median is different from median used by MMF algorithm. MMF median moves along the time series therefore we name it horizontal median. Median used by RMF applied to different time series at the same minute. Because usually for display purposes different time series are stacked vertically we name this median vertical.

V. Monitoring of the stability of measuring channels

During multiyear operation of particle monitors mean count rates continuously alter not only by solar modulation or possible entering of regions where Galaxy arms are sending abundant GCR from supernovae explosions, but also by such prosaic effects as electronic components aging. Therefore, to identify instrumental failures and to avoid exploration of the artifacts instead of new physics we have to monitor carefully and continuously detector parameters. In this paper, we present a simple method to do it by monitoring equalizing coefficients of monitor channels [2]. The monthly (or decade) plots of coefficients will help to find unstable channels. The channel mean count rates are changing due to solar modulation effects, in contrast, the equalizing coefficients should be stable despite changing means. Therefore, it will be much easier to detect non-stable channels by monitoring the plots of coefficients, than changing channel means. Figures 5 and 6 are an example of our approach.

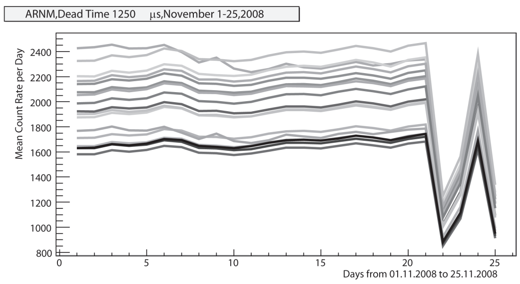

Fig. 5. Day-to-day changes of the mean values of Aragats Neutron Monitor; at November 22 there were power supply cut off

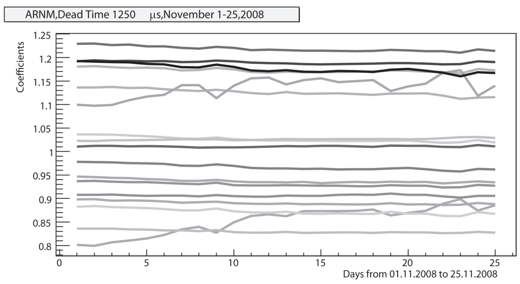

Fig. 6. Day-today changes of the channel coefficients of Aragats Neutron Monitor

Although from Fig. 5 we can notice that the variations of two channels are significantly larger than variations of the other 16, in Fig. 6 the behavior of the corresponding coefficients demonstrate failure of two channels much more pronounced. The same method can be implemented to check data from numerous detectors. We have taken pressure corrected data of different monitors for time period 24.10.2008-25.12.2008 and calculated coefficients for these seven time series,

[2]Analogical method was presented by Eroshenko, at NMDB collaboration meeting in Kiel, 2008 (see [6]).

according to equations 1−3. In Fig. 7 we present the median corrected, according to equation 3, data of NMDB Monitors (note, that the spikes in Nor Amberd and Izmiran monitors are filtered out and gaps are filled). In Fig. 8 we present the equalizing coefficients for all seven monitors calculated for each day of selected period. As you can see, 6 coefficients from 7 demonstrate very stable behavior, proving that all parameters of the neutron monitor chambers remain stable and constant. The calculated coefficients for the Athens monitor are much more variable. The high variability (non-coherence) of the Athens monitors coefficient may be caused by drift of the electronics parameters (including pressure sensor) in the end of 2008. When dealing with multiple remote sensors it is of vital importance to develop a number of quality tests to check continuously the data coming from different remote destinations. Although data the NMDB network detectors are similar, different groups use different data acquisition electronics, pressure sensors and data transfer protocols. The time history of the equalizing coefficients is one of such tests to help keep NMDB data reliable and adequate for further physical inference.

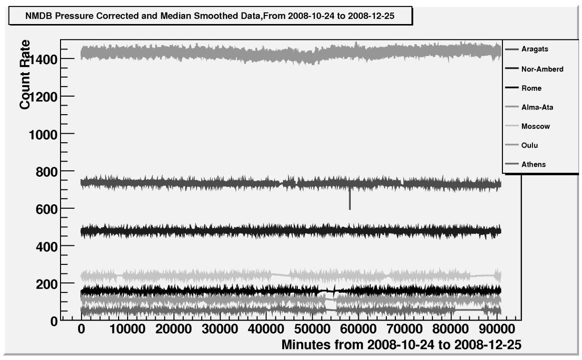

Fig. 7. Pressure Corrected and Median Smoothed Data from NMDB

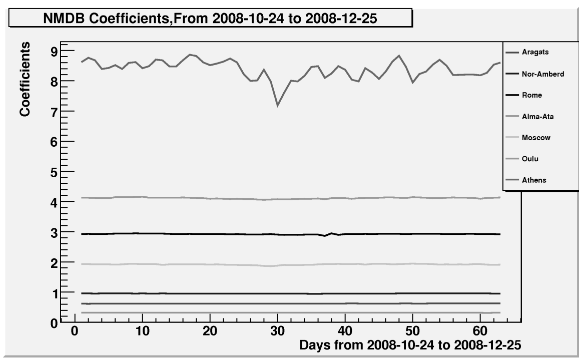

Fig. 8. Equalizing coefficients of the NMDB facilities

VI. Conclusion

Filtering of the multichannel data of particle detectors operated many years for detection of the solar modulation effects and, maybe, sidereal modulation effects, is of vital importance. During multiyear measurements, characteristics of detector undergo critic changes due to aging effects of sensors and discrete elements of electronics. Overabundance of the information allows introducing correction algorithms using stabilizing properties of the median of time series. Continuous storing and monitoring of the mean values of all channels along with their equalizing coefficient allows archiving of time-history of the behavior of all channels. Examining the relative behavior of channel means and coefficients during multiyear operation it became possible to distinguish the physical effects from instrumentation failures. See for example discussion in [8] and [9]. Also our approach allows not only correction of mistakes due to hardware malfunction, but simple and efficient method of timely detection of non-stable channels or/and mistakes in data bases collecting time series from different remote detectors.

VII. Acknowledgment

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