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Some alternative instrumentation for galactic cosmic rays measurement using ground based neutron monitor detectors

I. Elapsed time methods

V. Kollár[1,2], K. Kudela[1] and M. Minarovjech[1]

[1] *Institute of Experimental Physics SAS, Watsonova 47, 043 53 Košice, The Slovak Republic*

[2] *Astronomical Institute of the Slovak Academy of Sciences 059 60 Tatranská Lomnica, The Slovak Republic(E-mail: kollar@ta3.sk)*

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Abstract. We have measured the neutron monitor pulse distribution in time using alternative technique for the pulse registration. We describe the used instrumentation as well as analysis technique for the data processing. Our observations show that the acquired data sets are helpful to study the effects of galactic cosmic rays modulation.

Key words: galactic cosmic rays – energetic particles – cosmic rays modulation

1. Introduction

The primary galactic cosmic rays (GCR) consist mainly of high energetic protons, alpha particles and heavier nuclei. The primary GCR are influenced by the galactic, interplanetary, magnetospheric and geomagnetic magnetic fields when approaching the Earth. The GCR flux is modulated by solar activity. Its evidence is an 11 year GCR cycle in the "antiphase" with solar activity and further solar influences. Upon approaching the atmosphere the primary GCR are subject to strong interactions with the atmospheric mass. Local particle showers of mesons and other secondary particles are produced in the collisions. Energetic GCR primary particles continue to propagate in the atmosphere and interact successively, producing more and more secondary particles along their trajectories. An electrically charged secondary cosmic ray particle produced in the atmosphere is also subject to geomagnetic effects. According to Dorman (1974), the intensity of the i-th secondary cosmic ray particle at a point with rigidity $\Re_c$ at atmospheric depth h will be

$$I_i(\Re_c, h) = \int_{\Re_c}^{\infty} W_i(\Re, h) d\Re + \int_{\Re_c}^{\infty} m_i(\Re, h) \Delta D(\Re) d\Re \ , \qquad (1)$$

where $D(\Re)$ is differential energetic spectrum of the primary GCR with rigidity $\Re$, $m(\Re, h)$ is the integral generation multiplicity of secondary particles, and $W(\Re, h)$ is a relevant non-normalized coupling coefficient.

Neutron monitors (NMs) rank among the most widely used instruments for the GCR measurements. The NMs measure by proxy the intensity of GCR approaching the Earth and its variations in time. In general, the output pulses from the detector of GCR originate from neutrons emerging as the reaction product of hadronic collisions of secondary GCR energetic particles and lead target material surrounding the monitor. Bieber et al., (2004 and references therein) and references therein have shown that the number of emerging neutrons can be approximately estimated as

$$\nu_n = 25E^{0.4}, \tag{2}$$

where ν_n is the average number of emerging neutrons and E is the energy (GeV) of the incident energetic particle. Detecting an emerged neutron in a monitor depends on its initial energy and location. The detection efficiencies range from 2% to 10% for an emerged neutron energy in the range 20 MeV to 0.2 MeV. The resulting calculation yielded detection efficiencies ranging from 2% for a 20 MeV evaporation neutron to 10% at 0.2 MeV with 6.5% at 2.5 MeV (the mean evaporation neutron energy for a Pb interaction). Efficiency decreases with energy because of decrease of the cross section for interaction ^{10}B(n,α)^{7}Li (see Figure 2 in the paper by Clem and Dorman, 2000).

2. Methods and data

The super neutron monitor at Lomnický štít (geographic latitude 49.20 N, geographic longitude 20.22 E, cutoff rigidity 3.84 GV, altitude 2634 meters above see level) has been used to study features of the temporal changes in the pulse distribution of the galactic cosmic rays isotropic intensity variations. More details on the monitor system can be found in Kudela *et al.* (2000). Figure 1 shows the output configuration of used counter units. The output pulses from the neutron counters are amplified and shaped to 16 μsec duration. The ordinary one minute readings are performed by employing the counter outputs 1 to 8 recorded by SAPI and/or channel outputs A to D recorded by SMP electronic instrumentation, respectively.

The aim of this paper is to present and analyze temporal changes in the counter pulses distribution caused by the GCR intensity modulations. To this end, we designed and built additional electronic equipments at the Lomnický štít cosmic ray observatory. Employing this additional electronic instrumentation, we can measure and record the number of counter or channel output pulses within a short time interval (method m10) and the time interval between two successive pulses (method m140). In Figure 2, we show the time intervals when the m10 and m140 data are observed.

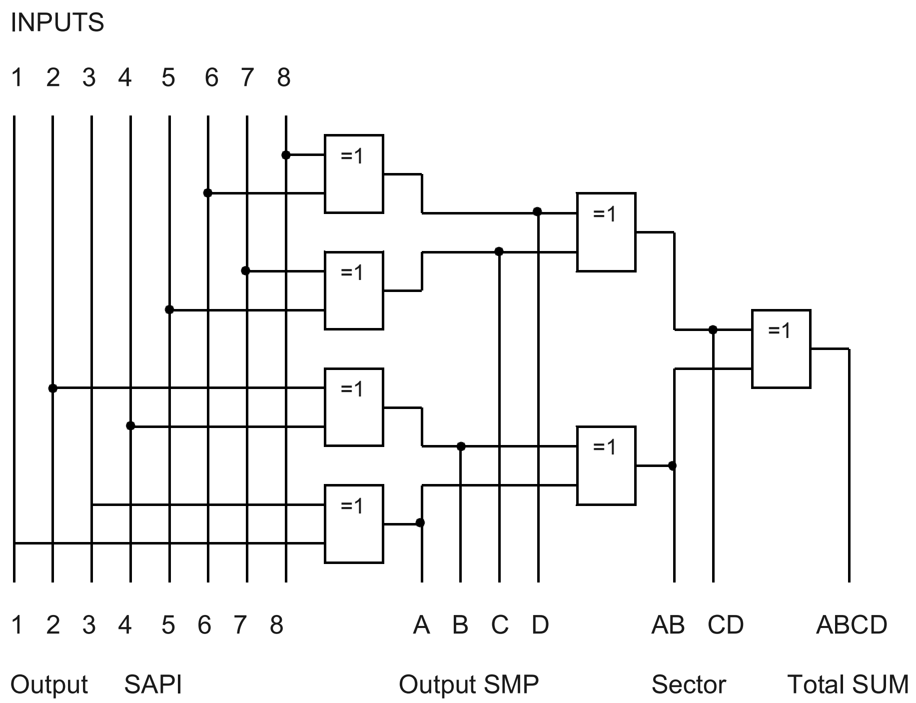

Figure 1. Digital distributor and summator.

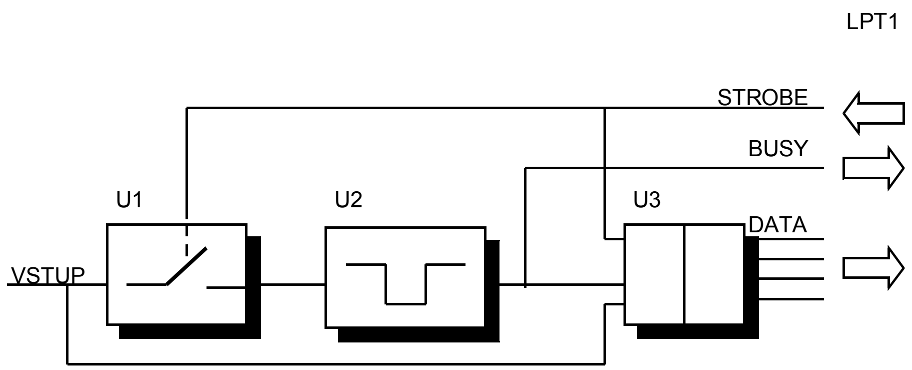

Figure 2. Lomnický štít cosmic rays daily data corrected to standard pressure (solid line). Time segments of the measured m10 data are depicted by the bottom black squares area. The top black squares area depicts the time segments for the measured m140 data.

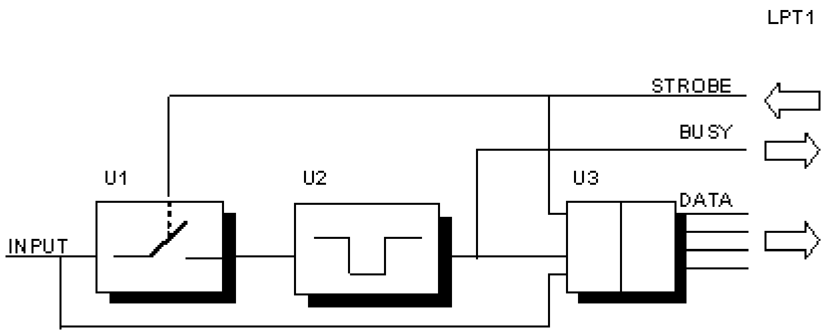

Figure 3. Block circuit.

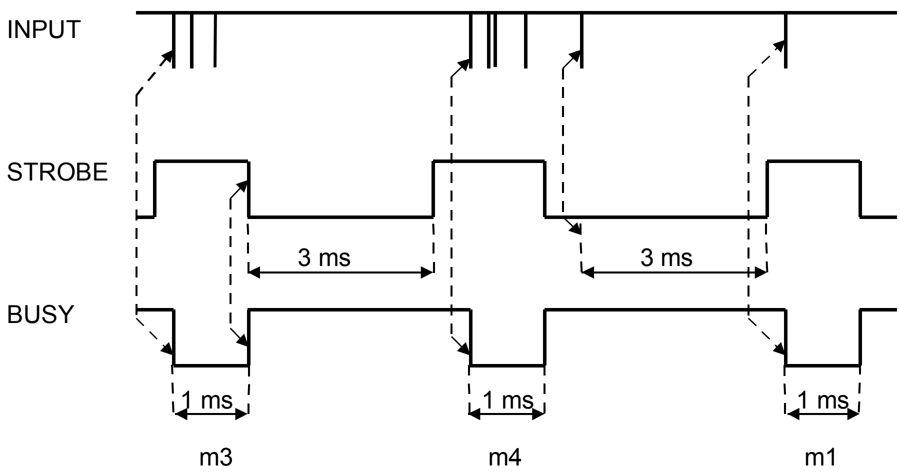

Figure 4. Timing diagram for the m10 method.

2.1. Method m10

The suggestion of this method was motivated by the paper of Marsden et al. (1964). The m10 data acquisition system for measuring the number of neutron counter pulses within a short time interval is based on simple external electronic circuits. The electronic block circuit is shown in Figure 3. Pulses from the neutron counter come to a gating circuit U_1 and counting input of the digital counter U_3 with a latch. The output latch data are transmitted on to the data bus of the computer parallel printer port (LPT). The STROBE data on the LPT output and the LPT input data BUSY are used as the control signals features of the data acquisition process. If the gating signal STROBE is on, the

Table 1. An example of the readings of number of pulses for a m10 method.

DOY	$hhmm$	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}
001	0001	03590	0804	0203	0075	014	009	000	001	000	001
001	0002	03584	0804	0199	0063	021	005	002	001	001	001
001	0003	03493	0793	0188	0046	024	004	002	002	001	002
001	0004	03504	0778	0211	0068	022	009	001	000	001	000
001	0005	03623	0840	0183	0067	021	009	003	002	002	000
001	0006	03597	0856	0200	0051	019	006	003	000	000	000

incoming input neutron counter pulse triggers the mono-stable trigger circuit U_2 to generate a pulse with the pulse width of 1 *msec*. This generated pulse is sent to an LPT BUSY input. The leading edge of a generated pulse is resetting the digital counter to the zero state, enables counting pulses from the neutron counter, and finally, the trailing edge of the generated pulse disables counting pulses from the neutron counter and enables the U_3 latch outputs. The entire data acquisition process is driven by the computer software in the form of a never ending loop. To define the beginning of data acquisition processes, the time interval between the output LPT STROBE pulse and input BUSY pulse is controlled by software. Only if the controlled time interval is greater than or equal to 3 *msec* (during this time interval the neutron counter is inactive), the latched digital counter data are read and saved in the computer memory. The gating pulse width 1 *msec* and a time period of 3 *msec* were experimentally estimated by using long-term visual oscilloscopic observations of the neutron monitor pulses. Recorded m10 data at one minute intervals are saved to simple text files. An example of measured m10 data is given in Table 1. The day of year and time is stored in the first two columns of the table. Column 3 contains information on the number of single neutron counter pulse during 1 *msec* gating intervals per one minute, column 4 contains information on the number of two neutron counter pulses during 1 *msec* gating intervals per one minute, etc. The last column (12) contains the corresponding information for ten or more counter pulses.

2.2. Method m140

This method is inspired by the paper and obtained results of Bieber *et al.* (2001). The m140 method is based on measurements of the time between successive neutron counter pulses. By using the fast ATMEL AVR processors it is possible to measure the time between trailing edges of pulses. The time acquiring circuit has been realized as the internal PC ISA card, located inside the PC. Usual solution is to connect the neutron counter pulse stream to the processor's interrupt input. Generating interrupts from a trailing edge of an input pulse the interrupt will immediately break the current CPU routine and call the time

Table 2. An example of the readings of number of pulses for a m140 method.

DOY	*yy*	*hhmm*	*1*	*2*	*3*	*4*	*5*	...	*137*	*138*	*139*	*140*
218	04	0001	108	084	110	075	063	...	013	004	009	003
218	04	0002	104	124	100	087	075	...	005	003	004	006
218	04	0003	113	095	105	088	069	...	007	011	006	003
218	04	0004	128	108	079	080	077	...	003	004	015	004

measurement subroutine. Each measured time is saved as an event to one of the corresponding 140 data groups ranging from 10 μsec to 1400 μsec. For example, if the acquired time is greater than 20 μsec and smaller than or equal to 30 μsec, the contents of the third data group is increased by one. Recorded m140 data acquired at one minute intervals are saved to a simple text files. An example of measured m140 data is shown in Table 2. The date and time information as the day of year, two last digits of the year and time (hours and minutes) are stored in the first three columns of Table 2. The column 4 contains information about the number of time intervals shorter than or equal to 10 μsec between successive neutron counter pulses registered during one minute, the column 5 contains the number per one minute registered time intervals between successive neutron counter pulses longer than 10 μsec and shorter than or equal to 20 μsec, etc. The last column 144 contains information on the number per one minute registered time intervals between successive neutron counter pulses longer than 1390 μsec and shorter than or equal to 1400 μsec.

The number of events per minute with the time between the successive neutron counter pulses longer than 1400 μsec, is possible to calculate by subtraction of the sum of m140 group data in the corresponding row of the data table from the regular SAPI or SMP one minute data uncorrected for the standard atmospheric pressure.

Data obtained using the method m140 allow us to simulate the GCR data recorded by using any value of the dead time in the range from 10 to 1400 μsec. The corresponding SMP count rates are used as a SMP data with a short dead time, and the data with large dead time N*10 μsec are equal to the difference between the corresponding SMP data and the summation of the events numbers in groups 1 to N.

2.3. The relation between variations of the m10 data and atmospheric pressure

The four panels (a) to (d) in Figure 5 show time courses of 10-minute averages of pressure uncorrected SMP counting rates, m10, m140, pressure data and pressure corrected SMP data for 2007. The thick curve in panel (a) represents the measured pressure uncorrected counting rates of the SMP data (channel C), thin curve represents the first group of pressure uncorrected m10 data. Panel (b)

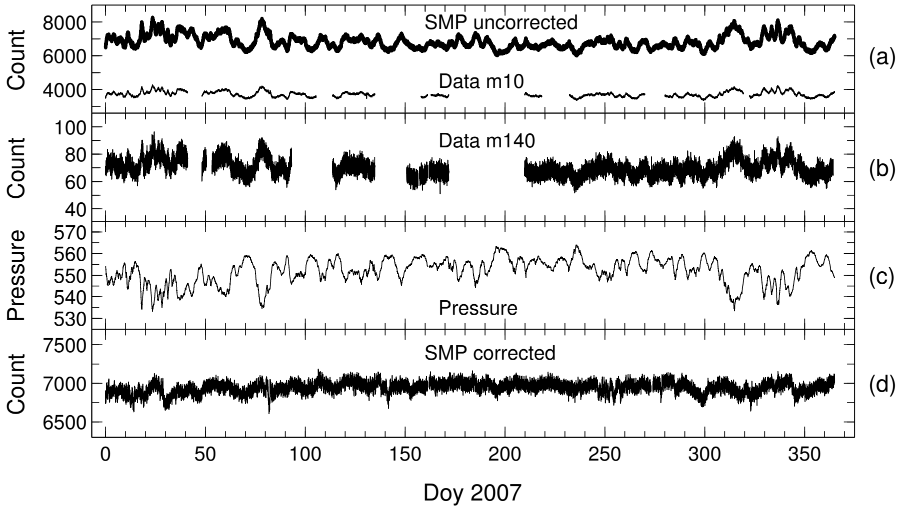

Figure 5. Variations of the 10-minute averages for the SMP, m10, m140 and pressure data measured during the year 2007. (Panel (a)): SMP chanel C pressure-uncorrected data (upper curve), pressure-uncorrected first group of m10 data (lower curve). (Panel (b)): pressure-uncorrected first group of m140 data. (Panel(c)): Atmospheric pressure variation. (Panel (d)): SMP chanel C presure-corrected data.

Table 3. Summary of *b10* values.

Group i	1	2	3	4	5
b_i	-0.00687	-0.01128	-0.01396	-0.01519	-0.01555
Δb_i	±0.000012	±0.000019	±0.000053	±0.000089	±0.000133
Group i	6	7	8	9	10
b_i	-0.01498	-0.01447	-0.01340	-0.01361	-0.01203
Δb_i	±0.000195	±0.000276	±0.000383	±0.000509	±0.000659

shows the first group of m140 pressure uncorrected data. Panel (c) represents the atmospheric pressure variations and panel (d) shows the SMP counting rate (channel C) corrected for atmospheric pressure. In Figure 5 we can see similar courses and different magnitudes of the plotted pressure uncorrected SMP counting rates, m10 and m140 data.

The yearly averaged distribution to different groups of the minute m10 data for 2007 is shown in Figure 6 (upper panel). The bottom panel of Figure 6 shows the same for the m140 data.

Correction for atmospheric pressure requires an individual approach to each group of m10 or m140 data. Figure 7 shows an example of the relationship

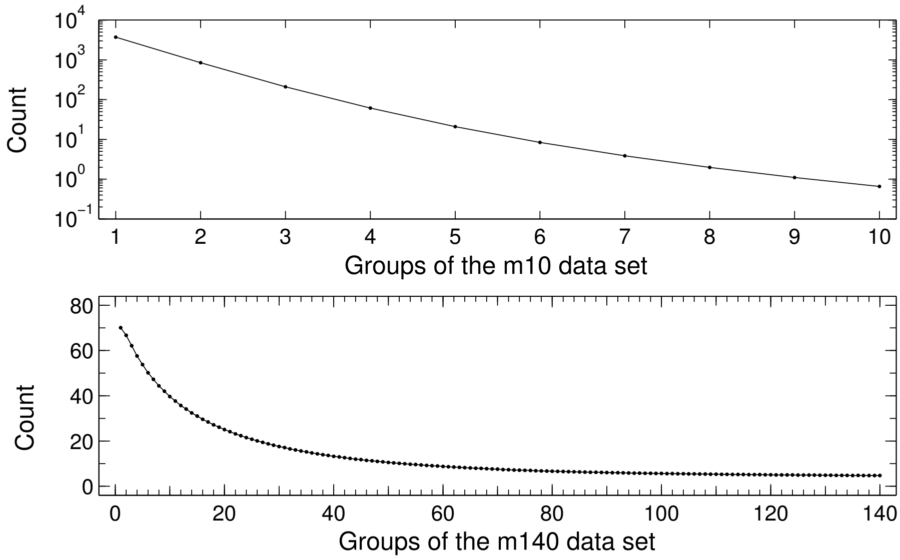

Figure 6. Mean minute values of the m10 data groups (upper panel) and m140 data groups (lower panel) for the year 2007.

between the 10-minute averages of the first group of m10 data, changes in atmospheric pressure and pressure corrected SMP channel C count rates. We use an exponential surface fitting procedure to determine the relationship between the 10-minute averages of the m10 data, atmospheric pressure variations and corrected for atmospheric pressure SMP channel C count rates. The solution of the equation in the form

$$Ic_i = a_i m_i e^{(b_i(p-p_0))}, \tag{3}$$

where Ic_i is rescaled/corrected for atmospheric pressure SMP channel C count rate, a_i is a linear factor close to one, m_i is the i-th group of m10 data values and $p - p_0$ is the corresponding pressure difference.

The solution of equation (1.3) defines the curved surface depicted as a mesh in Figure 7. Dark points on the mesh surface represent the SMP channel C count rates corrected for atmospheric pressure. Values of the exponent b_i for the method m10 determined from the 3-D fit are summarized in Table 3 and depicted in Figure 8 (left panel). The exponents b_i for the method m140 are plotted in Figure 8 (right panel). We can see that the values b_i for each group defining the m10 and m140 approximate correction of the data m for the atmospheric pressure, are different for different groups and methods.

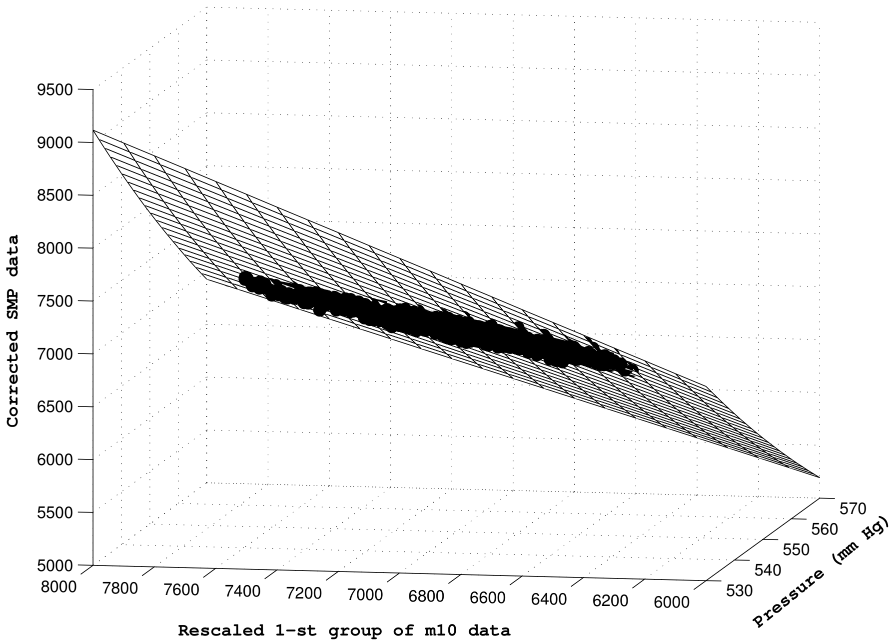

Figure 7. Pressure corrected values of SMP data (dotted black area) versus pressure uncorrected values of the m10 1-st data group and pressure variations for the year 2007.

3. Summary

The alternative time-elapsed methods m10 and m140 have been shortly reported. In the period 2001 - 2008 there were obtained long-term observational series of uncorrected GCR data by using the methods m10 and m140. Data obtained using the method m140 allow us to simulate the large dead time pressure uncorrected GCR data. In order to examine time variations of the GCR by the m10 and m140 data groups, it is necessary to properly correct m10 and m140 data for atmospheric pressure. The obtained pressure corrected data allow us to analyze the variation of GCR registered in different groups of data for different phases of the solar cycle and solar activity, which will be the subject of further work.

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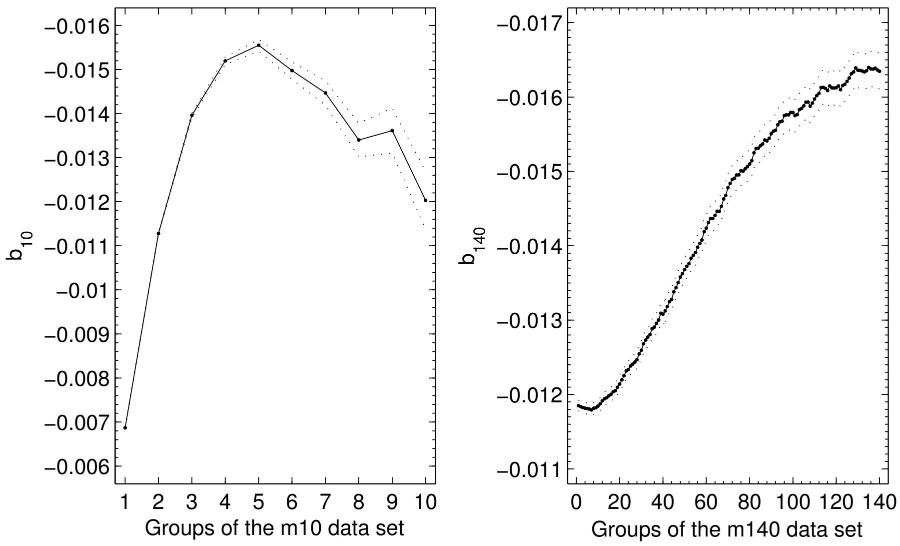

Figure 8. A dotted solid line depicts the yearly averaged b_{10} values (left panel) and b_{140} values for the year 2007 and the corresponding groups. The dotted thin lines represent a 0.95 confidence level

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