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Barometric coefficients for different neutron multiplicities according to ESO NM data (Israel) and data of University "Roma Tre" NM (Italy)

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Abstract. On the basis of hourly data obtained by neutron monitor (NM) of Emilio Segre' Observatory (height 2025 m above s. l., cut-off rigidity for vertical direction 10.8 GV) and by NM of University "Roma Tre" (about sea level, cut-off rigidity 6.7 GV) we determine barometric coefficients both stations for total neutron intensity and for multiplicities $m \geq 1$, $m \geq 2$, $m \geq 3$, $m \geq 4$, $m \geq 5$, $m \geq 6$, $m \geq 7$, and $m \geq 8$, as well as for m=1, m=2, m=3, m=4, m=5, m=6, and m=7. We determine also for each hour the effective multiplicity <m> for $m \geq 8$ and estimate the barometric coefficient for <m> for both NM sections. We used hourly data from June 1998 up to April 2001, and we excluded periods when above the NM of Emilio Segre' Observatory was snow. We compare obtained results with expected according to the theory of meteorological effects for total neutron component and for neutron multiplicities.

1 Introduction

Determination of cosmic ray barometric effect is very important for exact correction of observation data on barometric effect with taking into account its changing with cut-off rigidity and with solar activity cycle (see review in Dorman, 1957, 1963, 1972, 1974). Investigations of barometric effects dependence from cut-off rigidity give important possibility to determine barometric coefficients of integral multiplicities (differential barometric coefficients, introduced in Dorman, 1972). This research is also important for exact correcting of cosmic ray latitude survey data (Iucci et al., 2000). In Dorman et al. (1999a) attenuation coefficients for Emilio Segre' Observatory for total neutron intensity and for different multiplicities were determined in the first time approximately on the basis of measurements of air pressure, total neutron monitor counting rate and intensities of neutron multiplicities ≥1, ≥2, ≥3, ≥4, ≥5, ≥6, ≥7 and ≥8 in three points on different altitudes: port Haifa (sea level), at low station of sky lift (626 *mm* Hg), and on the final position of Emilio Segre' Observatory on Mt. Hermon (33°18.3′N, 35°47.2′E, 598 *mm* Hg, 2025 m above sea level, $R_c = 10.8\,GV$). Determined barometric coefficients were used in Dorman et al. (1999b) as basis for iteration processes for more exact determination of barometric coefficients by using hourly data for June-December 1998. By these data we determined approximately cosmic ray barometric coefficients for total neutron monitor counting rate, as well as separately for multiplicities 1, 2, 3, 4, 5, 6, 7, by taking into account also information on primary cosmic ray variations on the basis of Rome neutron monitor data. Here we will develop the method of determining of barometric coefficients for total neutron intensity and different multiplicities step by step in three approximations. As the first approximation we will use barometric coefficients determined by widely used correlation of cosmic ray data for all period of observations with variations of air pressure. Then obtained corrected on barometric effect in the first approximation data we correlate with Rome data, also corrected on the barometric effect. By obtained regression coefficients we correct our original data on cosmic ray primary variations. Corrected data we again correlate with air barometric pressure and determine barometric coefficients in the second approximation. Then with obtained barometric coefficients we correct our data on barometric effect with much better accuracy and new data of intensity again correlate with corrected Rome data. By obtained new regression coefficients we more exactly correct cosmic ray data of Emilio Segre' Observatory on primary variations. Then by data corrected on primary variations in the second approximation we determine barometric coefficients for total neutron intensity and different multiplicities in the third approximation.

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2 Barometric Coefficients for Rome NM.

In the first we determined by regression method barometric coefficients for total intensity and different multiplicities for Rome NM. Results for 1998-2001 are shown in Table 1.

Table 1. Barometric coefficients for total intensity and different multiplicities for Rome NM (in %/mmHg).

YEARS	1998	1999	2000	2001
$\langle h_o \rangle$, mmHg	761.97	760.63	761.41	759.57
TOTAL	-0.884 ±0.003	-0.942 ±0.003	-0.847 ±0.004	-0.926 ±0.007
$m=1$	-0.771 ±0.003	-0.836 ±0.003	-0.740 ±0.004	-0.820 ±0.007
$m=2$	-0.952 ±0.003	-1.009 ±0.004	-0.908 ±0.004	-0.993 ±0.008
$m=3$	-1.015 ±0.003	-1.068 ±0.004	-0.971 ±0.004	-1.051 ±0.008
$m=4$	-1.055 ±0.004	-1.103 ±0.004	-1.015 ±0.005	-1.086 ±0.008
$m=5$	-1.078 ±0.005	-1.116 ±0.005	-1.037 ±0.005	-1.108 ±0.009
$m=6$	-1.096 ±0.003	-1.120 ±0.003	-1.063 ±0.004	-1.108 ±0.007
$m=7$	-1.094 ±0.009	-1.143 ±0.009	-1.054 ±0.009	-1.126 ±0.014
$m \geq 8$	-1.091 ±0.007	-1.115 ±0.007	-1.065 ±0.006	-1.124 ±0.011

3. Barometric Coefficients for ESO NM (Mt. Hermon) in the First Approximation.

As the first approximation for barometric coefficients for ESO NM for total intensity and different multiplicities we used as usual regression coefficients in the relation between change of atmospheric pressure $h-h_o$ and natural logarithms of NM counting rates of observed total neutron intensity and of different multiplicities $\ln(I_m(h))^{ESO}_{obs}$:

$$\ln(I_m(h))^{ESO}_{obs} = B_{m1} \times (h-h_o) + C_{m1} \qquad (1)$$

where $m = total, 1, 2, 3, 4, 5, 6, 7, \geq 8$. We used hourly data from June 1998 up to April 2001. For each m we determined also correlation coefficients R_{m1}. Results are listed in Table 2. From this Table can be seen that in case when data are not corrected on primary variations, the correlation between the change of atmospheric pressure and cosmic ray intensity in different channels is very low, especially for a big multiplicities.

Table 2. Barometric coefficients B_{m1} in the first approximation for total intensity and for different multiplicities for ESO NM. Also are shown corresponding correlation coefficients R_{m1}.

CHANNEL	B_{m1}, %/mmHg	R_{m1}
TOTAL	-0.855±0.008	0.6438
$m=1$	-0.676±0.008	0.5827
$m=2$	-0.905±0.009	0.6145
$m=3$	-1.015±0.010	0.6415
$m=4$	-1.093±0.010	0.6628
$m=5$	-1.154±0.011	0.6655
$m=6$	-1.201±0.012	0.6323
$m=7$	-1.243±0.015	0.5693
$m \geq 8$	-1.301±0.015	0.5797

4. The Second Approximation for Barometric Coefficients for ESO NM (Mt. Hermon).

By found barometric coefficients for ESO NM listened in Table 2 we correct observed data according to relation

$$\ln(I_m)^{ESO}_{cor1} = \ln(I_m(h))^{ESO}_{obs} - B_{m1}(h-h_o) - C_{m1}. \qquad (2)$$

The corrected according to Eq. (2) data we correlate with Rome NM data also corrected on barometric effect by barometric coefficients listed in Table 1. The results can be described by relations

$$\ln(I_m)^{ESO}_{cor1} = \ln(I_t)^{Rome}_{cor1} \times D_{m1} + E_{m1}, \qquad (3)$$

where regression coefficients are listen in Table 3 (together with corresponding correlation coefficients).

Table 3. Regression coefficients D_{m1}, E_{m1} and correlation coefficients Ω_{m1} for connection of ESO NM data with Rome NM data according to Eq. (3).

channel	D_{m1}	E_{m1}	Ω_{m1}
total	0.669±0.002	4.635±0.024	0.946
m=1	0.613±0.002	4.577±0.025	0.935
m=2	0.740±0.006	1.758±0.076	0.717
m=3	0.750±0.007	0.548±0.086	0.677
m=4	0.708±0.007	0.130±0.097	0.611
m=5	0.627±0.008	0.378±0.110	0.515
m=6	0.533±0.010	0.859±0.129	0.400
m=7	0.409±0.012	1.831±0.155	0.267
m≥8	0.099±0.013	6.095±0.165	0.063

Then by found regression coefficients D_{m1} and E_{m1} we determine cosmic ray variations on Mt. Hermon corrected on primary variations according to:

$$\ln(I_m)^{ESO}_{cor1/pr} = \ln(I_m)^{ESO}_{obs} - \ln(I_t)^{Rome}_{cor1} \times D_{m1} - E_{m1} . \quad (4)$$

Now we can determine the 2-nd approximation of barometric coefficients according to regression relations:

$$\ln(I_m(h))^{ESO}_{cor1/pr} = B_{m2} \times (h - h_o) + C_{m2} \quad (5)$$

Barometric coefficients B_{m2} and corresponding correlation coefficients R_{m2} are listen in Table 4.

Table 4. Barometric coefficients B_{m2} in the second approximation for total intensity and for different multiplicities for ESO NM. Also are shown correspondingly correlation coefficients R_{m2}.

channel	B_{m2}	R_{m2}
total	-0.904±0.003	0.941
m=1	-0.721±0.003	0.909
m=2	-0.958±0.003	0.934
m=3	-1.069±0.004	0.918
m=4	-1.145±0.005	0.876
m=5	-1.200±0.007	0.805
m=6	-1.240±0.010	0.711
m=7	-1.273±0.014	0.604
m≥8	-1.308±0.015	0.584

5. The Third Approximation for Barometric Coefficients for ESO NM (Mt. Hermon).

By found barometric coefficients for ESO NM listened in Table 4 we correct observed data according to relation

$$\ln(I_m)^{ESO}_{cor2} = \ln(I_m(h))^{ESO}_{obs} - B_{m2}(h - h_o) - C_{m2} . \quad (6)$$

The corrected according to Eq. (6) data we correlate with Rome NM data also corrected on barometric effect. The results can be described by relations

$$\ln(I_m)^{ESO}_{cor2} = \ln(I_t)^{Rome}_{cor1} \times D_{m2} + E_{m2} , \quad (7)$$

where regression coefficients are listen in Table 5 (together with corresponding correlation coefficients).

Table 5. Regression coefficients D_{m2}, E_{m2} and correlation coefficients Ω_{m2} for connection of ESO NM data with Rome NM data according to Eq. (7).

channel	D_{m2}	E_{m2}	Ω_{m2}
total	0.670±0.002	4.612±0.024	0.947
m=1	0.615±0.002	4.556±0.024	0.936
m=2	0.768±0.002	1.276±0.027	0.950
m=3	0.782±0.003	0.010±0.034	0.925
m=4	0.740±0.004	-0.399±0.046	0.861
m=5	0.660±0.005	-0.176±0.065	0.733
m=6	0.569±0.007	0.288±0.090	0.556
m=7	0.446±0.009	1.245±0.123	0.357
m≥8	0.140±0.010	5.473±0.133	0.110

Then by found regression coefficients D_{m2} and E_{m2} we determine cosmic ray variations on Mt. Hermon corrected on primary variations according to:

$$\ln(I_m)^{ESO}_{cor2/pr} = \ln(I_m)^{ESO}_{obs} - \ln(I_t)^{Rome}_{cor1} \times D_{m2} - E_{m2} \quad (8)$$

Now we can determine the 3-rd approximation of barometric coefficients according to regression relations:

$$\ln(I_m(h))^{ESO}_{cor2/pr} = B_{m3} \times (h - h_o) + C_{m3} \quad (9)$$

Barometric coefficients B_{m3} and corresponding correlation coefficients R_{m3} are listen in Table 6.

Table 6. Barometric coefficients B_{m3} in the second approximation for total intensity and for different multiplicities for ESO NM. Also are shown corresponding correlation coefficients R_{m3}.

channel	B_{m3}	R_{m3}
total	-0.904±0.003	0.941
m=1	-0.721±0.003	0.909
m=2	-0.960±0.003	0.935
m=3	-1.072±0.004	0.919
m=4	-1.147±0.005	0.877
m=5	-1.202±0.007	0.806
m=6	-1.243±0.010	0.712
m=7	-1.275±0.014	0.605
m≥8	-1.311±0.015	0.585

6. Discussion and Conclusions

Let us compare three approximations of found barometric coefficients for ESO NM for total neutron intensity and different multiplicities (see Table 7) and corresponding correlation coefficients (Table 8).

Table 7. Comparison of three approximations of barometric coefficients for ESO NM for total neutron intensity and different multiplicities (in %/mm Hg).

channel	B_{m1}	B_{m2}	B_{m3}
total	-0.855±0.008	-0.904±0.003	-0.904±0.003
m=1	-0.676±0.008	-0.721±0.003	-0.721±0.003
m=2	-0.905±0.009	-0.958±0.003	-0.960±0.003
m=3	-1.015±0.010	-1.069±0.004	-1.072±0.004
m=4	-1.093±0.010	-1.145±0.005	-1.147±0.005
m=5	-1.154±0.011	-1.200±0.007	-1.202±0.007
m=6	-1.201±0.012	-1.240±0.010	-1.243±0.010
m=7	-1.243±0.015	-1.273±0.014	-1.275±0.014
m≥8	-1.301±0.015	-1.308±0.015	-1.311±0.015

Table 8. Comparison of correlation coefficients R_{m1}, R_{m2} and R_{m3} for ESO NM data correlation with air pressure.

channel	R_{m1}	R_{m2}	R_{m3}
total	0.6438	0.941	0.941
m=1	0.5827	0.909	0.909
m=2	0.6145	0.934	0.935
m=3	0.6415	0.918	0.919
m=4	0.6628	0.876	0.877
m=5	0.6655	0.805	0.806
m=6	0.6323	0.711	0.712
m=7	0.5693	0.604	0.605
m≥8	0.5797	0.584	0.585

From Tables 7 and 8 can be seen that: 1) for total neutron intensity and for small multiplicities (up to m=4) the second approximation has much better accuracy than the first approximation, statistical errors decrease in 2-3 times from the first to the second approximation and correlation coefficients increase very much (it means that for these NM channels correction on primary variations is very important); 2) for higher multiplicities (m≥5) the second approximation has about the same accuracy as the first approximation and correlation coefficients increase not so much (for these multiplicities the accuracy is determined mostly by poor statistics, correction on primary variations is not so important); 3) the difference between second and third approximations is negligible, correlation coefficients and statistical errors are about the same and very small differences of barometric coefficients for total neutron intensity and for different multiplicities are in frame of statistical errors (it means that two approximations for determining barometric coefficients is enough, the third approximation is necessary to made for control of obtained results).

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