Attenuation Coefficients for SVIRCO Observatory Data

M. Laurenza, M. Storini, S. Massetti

***Abstract*—Neutron monitor data from the SVIRCO (Studio Variazioni Intensità Raggi Cosmici) Observatory (Rome, IFSI-INAF/Roma Tre University) from 1998 to 2005 were used to derive the yearly attenuation coefficient (α). Briefly, α was estimated by using: - (i) the daily averages of the pressure-uncorrected counting rates of Rome neutron monitor (N_i), and the ones of the corresponding atmospheric pressure (P_i); only days with data coverage greater than 75% (i.e. > 18 h) were considered. - (ii) the daily values of the pressure-corrected counting rates registered by Hermanus neutron monitor (auxiliary data). Each year data set was also divided into quarters: January-March, April-June, July-September, October-December to estimate α values for shorter periods and to compute the yearly α average, by using the standard error derived from every subset as a weighting factor. The computations were performed by using: - the standard method (i.e. by calculating the linear regression of an adequate amount pairs of values ln[N_i-No] and [P_i-Po], being No and Po the averages of the corresponding values); - the difference method (as above but after subtracting the corrected data of an auxiliary detector, in our case Hermanus data); - the auto-regressive method (applied after knowing the self-correlation first coefficient of the residuals from the standard method).**

***Index Terms*—Cosmic ray variations, neutron monitor data, pressure effects.**

I. Introduction

Counting rates of continuously operating cosmic ray detectors show different modulation types over short and long time intervals, some of them related to pressure and temperature variations in the terrestrial atmosphere. Temperature effects are generally small and neglected in neutron monitors (NMs), while changes of the atmospheric pressure hardly affect the NM counts. Pressure-induced effects depend on the cutoff rigidity measurement site and on the solar modulation level of the primary cosmic ray particles. The barometric modulation in NM counts induced by atmospheric pressure changes is about a factor ten greater than the original signal (in Arctic and Antarctic regions can exceed 50 hPa). Hence, a data correction is needed to separate the primary particle variation from the atmospheric induced ones. In first approximation, the NM data correction can be simply achieved referring the neutron counts to an hypothetical condition of constant pressure by means of an exponential law where the absorption (attenuation) of the incoming particle flux is proportional to the atmospheric pressure. A constant α is usually used to eliminate pressure induced variations at the standard pressure of the detector location. Nevertheless, it was demonstrated that the long-term α variability undergoes an 11-year cycle modulation (e.g. [1]-[4]). In the present paper we evaluate the yearly α values for the SVIRCO observatory (Fig. 1) data and compare the results with the α coefficients computed for measurements recorded by Hermanus NMs.

II. Method and Analysis

The attenuation coefficient is defined as

$$\alpha(P) = -\frac{1}{N}\frac{dN}{dP} \tag{1}$$

being N the neutron intensity (counts) and P the local atmospheric pressure. For small pressure variations ΔP we have that $\alpha(P) \approx \alpha$ and the previous equation can be easily integrated to obtain the relation

$$N_0 = N_i e^{\alpha\left(P_i - P_0\right)} \tag{2}$$

where N_0 is the 'corrected' neutron intensity referred to the 'standard' pressure P_0 (usually the local mean pressure) while N_i and P_i are respectively the neutron intensity and the pressure measured at the time t_i. Once α is known, it is possible to correct the observed neutron counts by means of eq. (2), compensating the local pressure variations. Examples of data correction with a constant α for Rome and Hermanus are reported in the bottom panel of Fig. 2 for 2003. The uncorrected data for the Rome (Hermanus) observatory and the local pressure is displayed in middle (upper) panel of Fig. 2. The α and P_0 values used in standard analysis for the two stations are reported in Table I together with their geographical coordinates and cutoff rigidity. An estimation of

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α can be obtained by calculating the linear regression of an adequate amount pairs of values N_i - P_i.

Fig. 1. – SVIRCO observatory at Roma Tre University.

TABLE I
CHARACTERISTIC PARAMETERS USED IN STANDARD ANALYSES FOR ROME AND HERMANUS OBSERVATORIES

Parameter	Rome	Hermanus
Latitude (°)	41.86 N	34.25 S
Longitude (°)	12.47 E	19.13 E
Cut-off rigidity (GV)	6.3	4.5
Height (m)	s.l.	26 m a.s.l.
α	0.70%/hPa	0.90%/mm Hg
Standard Pressure	1009.25 hPa	760 mm Hg

Introducing the variable $I_i=ln(N_i)$, eq.(2) can be expressed as

$$I_i - I_0 = -\alpha\left(P_i - P_0\right) \tag{3}$$

setting I_0 and P_0 equal to the averages of the corresponding observed values. By applying the least square method, we obtain:

$$\hat{\alpha} = -\frac{\sum_1^n\left(I_i - \overline{I}\right)\left(P_i - \overline{P}\right)}{\sum_1^n\left(P_i - \overline{P}\right)^2} \tag{4}$$

If the error over I_i is not known a priori the standard error of α can be estimated from the residuals

$$v_i = I_i - \overline{I} + \hat{\alpha}\left(P_i - \overline{P}\right) \tag{5}$$

under the hypothesis that these are independent:

$$D_{\hat{\alpha}}^2 = \frac{\sum_1^n v_i^2}{(n-2)\sum_1^n\left(P_i - \overline{P}\right)^2} \tag{6}$$

The error calculated from eq. (6) is underestimated when a serial correlation (also called self-correlation) of the residuals exists. The self-correlation in the residuals can be produced by variations in the neutron intensity (independent of pressure changes), mainly from primary fluctuations and from changes in the detector efficiency. Three procedures allow to reduce these effects:

1) subdividing the data into subsets (equal and with a sufficient number of values, e.g. subdividing an year into four trimesters) and then calculating the weighted average of the obtained values of α using the inverse of the standard error (D_α^2) as weight;

2) decreasing the primary fluctuation by subtracting the corrected data (N_i^{AUX}) of an auxiliary station

$$I_i=ln(N_i)-ln(N_i^{AUX}) \tag{7}$$

with a similar cutoff energy but also placed in a sufficiently remote location to avoid correlation between the local pressure changes of the two monitors;

3) filtering the data before to carry on the evaluation of α, in order to decrease the self-correlation of residuals.

The filtering of the data can be achieved by substituting the original values with others obtained from the former by means of a determined algorithm. In particular, we define the "autoregressive filter" as

$$\begin{cases} \tilde{P}_i = P_i - r_u P_{i-1} \\ \tilde{I}_i = I_i - r_u I_{i-1} \end{cases} \tag{9}$$

where P_i, P_{i-1}, I_i and I_{i-1} are respectively the original values (i-th and i–1-th) of the pressure and of the intensity logarithm, $\tilde{P}_i$ and $\tilde{I}_i$ the corresponding filtered values; r_u is the first self-correlation coefficient of residuals (v_i) obtained from the regression of the original data.:

$$r_u = \frac{\sum_2^n v_i \cdot v_{i-1}}{\sum_2^n v_i^2} \tag{10}$$

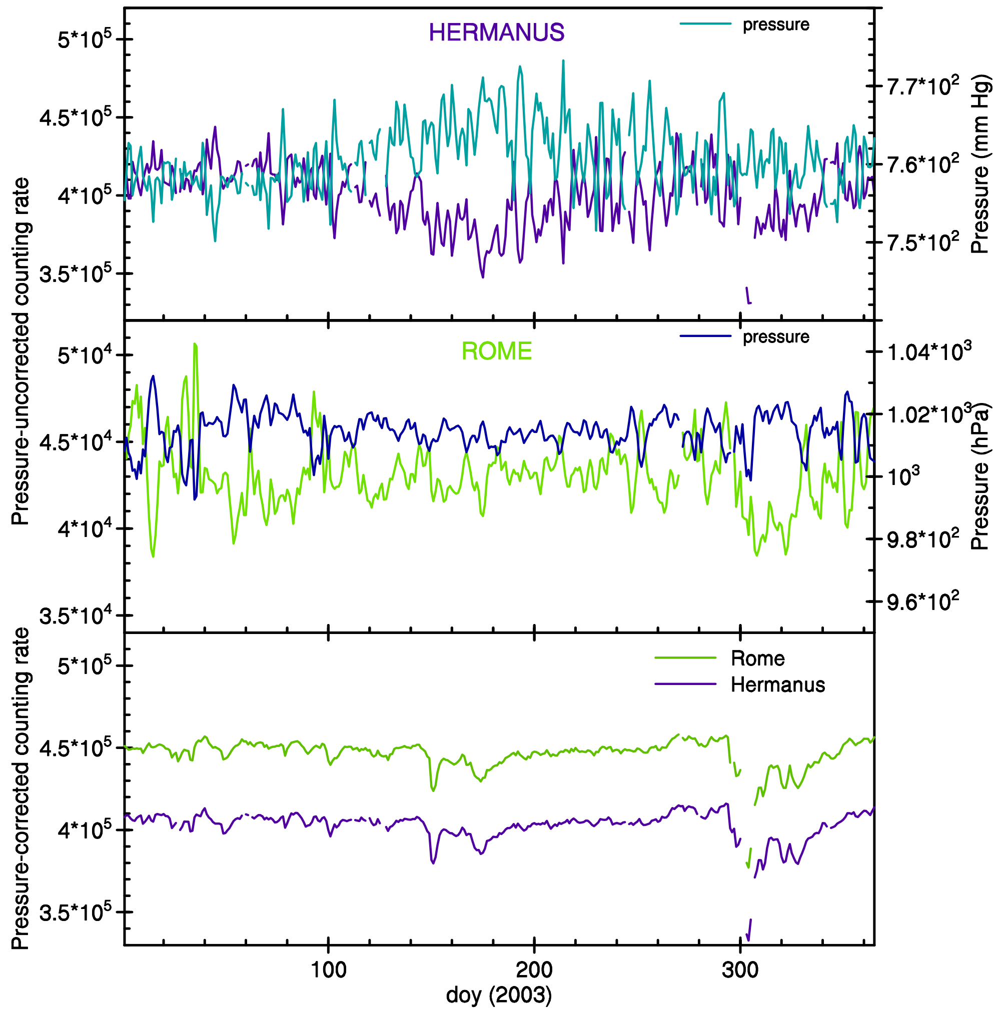

Fig. 2 – Time series of the pressure uncorrected counting rate with the atmospheric pressure for Hermanus (top panel) and Rome (middle panel) and of the pressure corrected counts for both the observatories (bottom panel).

In order to calculate α with the "autoregressive filter" it is necessary to make a preliminary regression of the original un-filtered data to evaluate r_u and then perform a second regression with the filtered data. Setting r_u=1 , we have the "difference filter" that is a particular case of eq. (9) and it operates a filtering independent from the distribution of residuals of the original data; hence its computation is simpler but rougher than the autoregressive filter. The combined use of the three methods results very effective. Beside the evident advantage in using an auxiliary station to decrease the primary fluctuations, the data filtering (e.g.: [1], [3]) can notably reduce the self-correlation of the residuals, lowering the error (eq. 6) and giving a best estimation of the attenuation coefficient. However, we compared the results obtained with all three methods described above (standard, difference and autoregressive). We analyzed daily mean counting rates recorded by SVIRCO detector; only days with a data coverage more than 75% (i.e. > 18 h) were considered. Days affected by GLEs were not included in the analysis. The yearly α was calculated for a complete solar cycle (n° 23) by applying the standard, difference and auto-regressive method. Note that NM counts of Hermanus observatory has been used as auxiliary data for its suitable geographic location (Table I). Middle panel in Fig. 3 shows the yearly α values as weighted averages of the four terms in which we subdivided each year (January-March, April-June, July-September, October-December). The upper panel displays the average pressure level and the number of days used in the analysis. The lower panel gives results from the complete yearly data set without the quarter division. The same analyses have been applied to Hermanus pressure-uncorrected data using Rome pressure-corrected counts as auxiliary data (Fig. 4).

From the results reported in Fig. 3 and Fig. 4 we can verify that:

1) the standard method, due to strong self-correlation of residuals, gives an attenuation coefficient that can fluctuate considerably; autoregressive and difference filters usually give results more steady in time, owing to a small self-correlation of residuals, and they are consistent each other considering the error estimates;

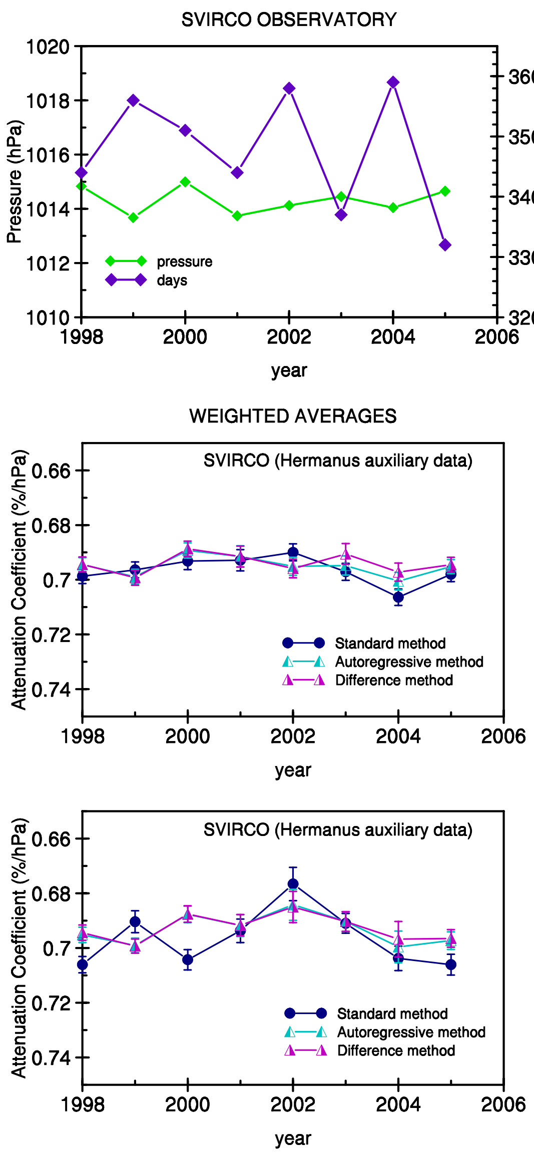

Fig. 3 – Time history of the yearly α coefficients computed from daily SVIRCO pressure uncorrected data (bottom panel) and from the quarter division (middle panel) by three different methods. The upper panel depicts the yearly average pressure and number of days used in the analyses vs time.

2) the α trends for both Hermanus and Rome are quite similar; in particular they are constant (considering the error Δα) from 2000 to 2002

III. Conclusion

The α variability was estimated for Rome and Hermanus neutron monitor data during the period 1998 - 2005. Our results are consistent with previous findings (0.70 %/hPa for Rome and 0.95 mm Hg for Hermanus). Nevertheless, the α dependence on the solar activity is less pronounced in cycle 23 than in the previous ones, as found by reference [4]. In particular, we did not find a clear evidence for the Gnevyshev gap in the α feature during the solar maximum phase (1999-2002).

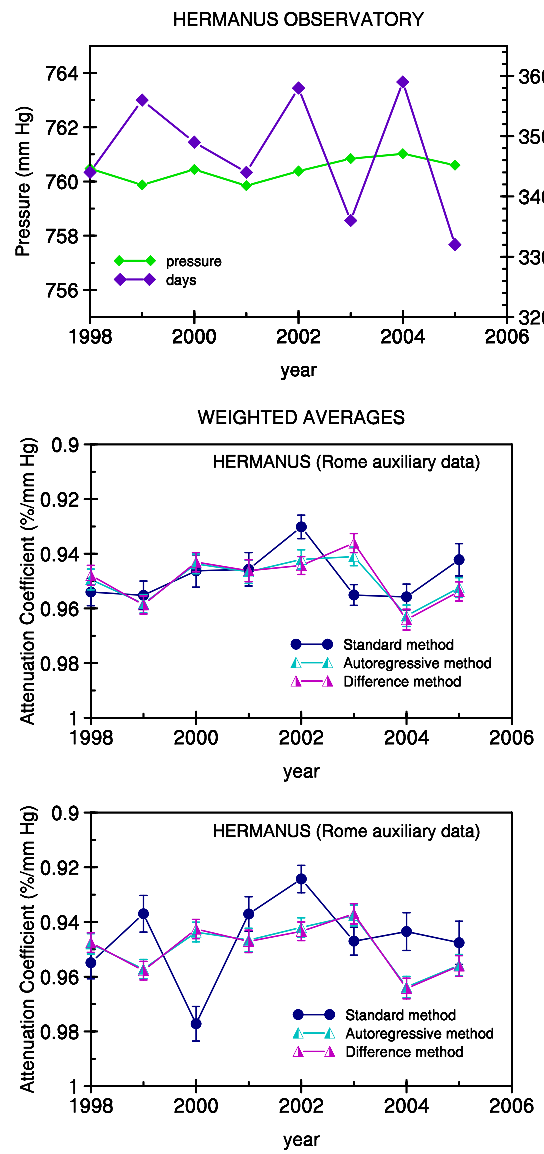

Fig. 4 – As in Fig. 3 for Hermanus data.

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References

[1] F.,Bachelet, E. Dyring, N. Iucci and G. Villoresi, “Synoptic study of the attenuation coefficients for the cosmic-ray neutron monitors of the IGY network from 1957 to 1965”, *Nuovo Cimento LIIB*, vol. 1, pp. 7646, 1967.

[2] M. Storini, S. Massetti, E. G. Cordaro, “The Gnevyshev Gap in the error of the atmospheric coefficient for neutron monitor data”, in Col acino, M., Giovanelli, G. (Eds.), *8th Workshop Italian Reasearch on Antarctic Atmosphere*, SIF Conference Proceedings, vol. 69, Bologna, pp. 251-259, 2000.

[3] S. Massetti, M. Storini, , E. G. Cordaro, ”The attenuation coefficient for Oulu neutron monitor”, in *Proc. of ICRC 2001*, pp. 3852-3855.

[4] M. Storini, K. Kudela, E. G. Cordaro, S. Massetti, “Ground-level enhancements during solar cycle 23: results from SVIRCO, LOMNICKY STIT and LARC neutron monitors”, *Adv. Space Res*., vol. 35, pp. 416-420, 2005.