

Calgary neutron monitor efficiency factor estimation after major renovation

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Abstract

Neutron monitor data which are used for studies of long-term variations, require a means for correcting for changes in efficiency following major renovations. We propose a means to obtain the required “efficiency factor” using multiple regression which, to a first-order approximation, considers solar modulation as well as any changes in the Neutron Monitor sensitivity over time.

1. Introduction

The Calgary neutron monitor has been in operation since the 1960s. Digital records have been available since 1979. Operations were suspended from 2009 until major renovations were completed in 2017. In order to share data with the Neutron Monitor Data Base (NMDB) an “efficiency factor” must be provided whenever operating conditions have changed. To normalize our data before and after the gap, account must be taken of the cycles of solar activity which modulate the arriving galactic cosmic rays. In addition, any long-term drift in the sensitivity of the detectors or other time-dependent variations should be included.

2. Method

[Fig. 1](#) shows the variation of the count-rates of the Calgary neutron monitor over the years of interest and, for comparison, the solar cycles as revealed by monthly sunspot numbers. Following the multiple regression technique (Cooper 1969), we assume that the NM count rates c_i to the first order of approximation is given by:

$$c_i = T \cdot t_i + S \cdot s_i + E + r_i,$$

where t_i are elapsed times (number of months since the beginning of the observation), s_i to be some convenient measure of solar activity (sunspot number from the website <http://www.sidc.be/silso/home>, last accessed July 4, 2023). E is the constant level sought, and r_i is the residual error. Finally, we chose c_i to be the NM pressure-corrected monthly average count rate.

Minimizing the sum of residual error squares, we obtain and solve a matrix equation in the form:

$$\begin{pmatrix} \sum_i (c_i - \bar{c})(t_i - \bar{t}) \\ \sum_i (c_i - \bar{c})(s_i - \bar{s}) \end{pmatrix} = \begin{pmatrix} \sum_i (t_i - \bar{t})^2 & \sum_i (t_i - \bar{t})(s_i - \bar{s}) \\ \sum_i (t_i - \bar{t})(s_i - \bar{s}) & \sum_i (s_i - \bar{s})^2 \end{pmatrix} \times \begin{pmatrix} T \\ S \end{pmatrix} = (M_{TS}) \times \begin{pmatrix} T \\ S \end{pmatrix}$$

Then the inverse matrix $(M_{TS})^{-1}$ provides estimates of the variance and covariance of the parameters when multiplied by the residual variance about the fit.

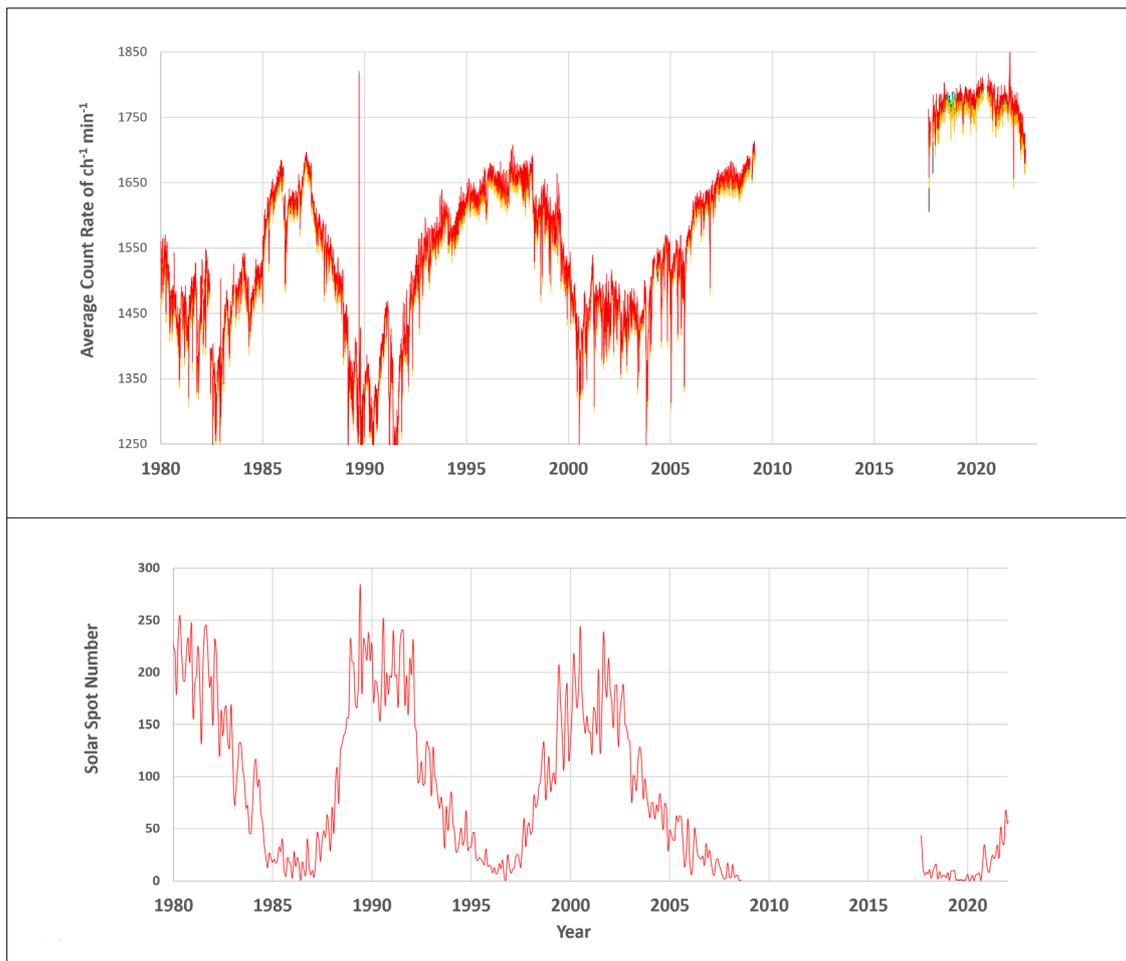


Fig. 1: Calgary NM mean count-rate change due to new data acquisition system.

3. Results

Values of the constants T (time), S (solar activity), and E (constant shift) and their respective standard deviations were obtained in the multiple regression calculations for two consecutive time periods and are shown in Tab. 1. Subscripts appended to the constants indicate the first or second period. The T_1 value may reflect not only drift in the count rate due to a decrease in detector sensitivity but also gradual changes in solar modulation. As a test, an artificial steady drift ($= 0.01 \cdot t$) was subtracted from the actual count rates for the 29-year data and was exactly reflected in the new computed value of T_1 (not shown here). However, there was no resultant change in either S_1 or E_1 . Despite the few years of data during decreased solar activity (2017-22), the values for S_1 and S_2 are remarkably close within error estimates.

Tab. 1: Constants T , S , and E evaluated before (column 1) and after (column 2) Calgary NM major renovations.

1979–2008	2017–2022
$S_1 = 1.494 \pm 0.066$	$S_2 = 1.392 \pm 0.215$
$T_1 = 0.006 \pm 0.036$	$T_2 = 0.345 \pm 0.142$
$E_1 = 1625.6 \pm 63.2$	$E_2 = 1783.8 \pm 16.1$

Fig. 2 shows the results of applying the calculated first-order correction for solar activity. The standard deviation of the ratio E_2/E_1 is given by the standard formula:

$$\sigma_R = \frac{E_2}{E_1} \sqrt{\left(\frac{\sigma_{E1}}{E_1}\right)^2 + \left(\frac{\sigma_{E2}}{E_2}\right)^2}$$

where any covariance σ_R has not been included. Inserting values from the previous slide, we obtain the estimation of the ratio E_2/E_1 and its standard deviation:

$$E_2/E_1 = 1.097 \pm 0.042$$

We conclude therefore that the renovation of the NM has resulted in an increase in the pressure-corrected count rate. However, it should be noted that the latest data coincides with several years of minimum solar activity only.

In order to verify this multiple regression method, we performed the same procedure by splitting Calgary data from 1979 to 2008 into two equal blocks. Again, the constants T , S , and E and their respective standard deviations are shown in Tab. 2. A few high values of solar activity during the early months may be responsible for the negative T_2 value. Future data points will hopefully clarify this statement.

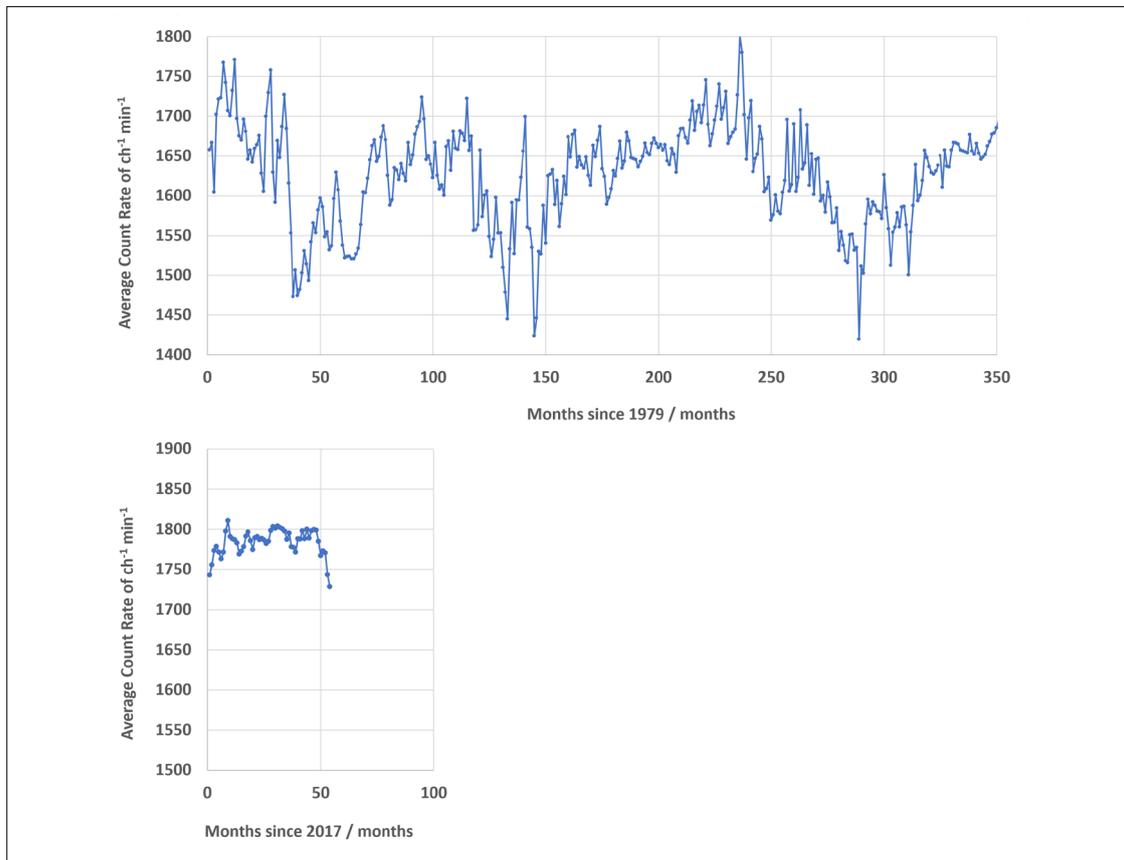


Fig. 2: Count rates after 1st order fit for solar activity.

Tab. 2: Multiple regression method validation results.

1979–1994	1994–2008
$S_1 = 0.996 \pm 0.046$	$S_2 = -1.133 \pm 0.039$
$T_1 = -0.309 \pm 0.073$	$T_2 = -0.250 \pm 0.047$
$E_1 = 1633.26 \pm 68.5$	$E_2 = 1664.6 \pm 54.7$

The ratio E_1/E_2 is, assuming the neutron monitor kept the same efficiency, should be close to unity. The value we obtained was:

$$E_1/E_2 = 0.981 \pm 0.052$$

Details are shown in Fig. 3.

A further application of this method would provide relative baseline count rates for different neutron monitors and provide a means of estimating the effects of different cut-off rigidities, altitude, and instrumental differences. A trial has been made comparing data over the 29-year period (1979-2008) from the NMs at Oulu and Calgary yielding the result:

$$E_{\text{Oulu}}/E_{\text{Calgary}} = 0.325 \pm 0.014$$

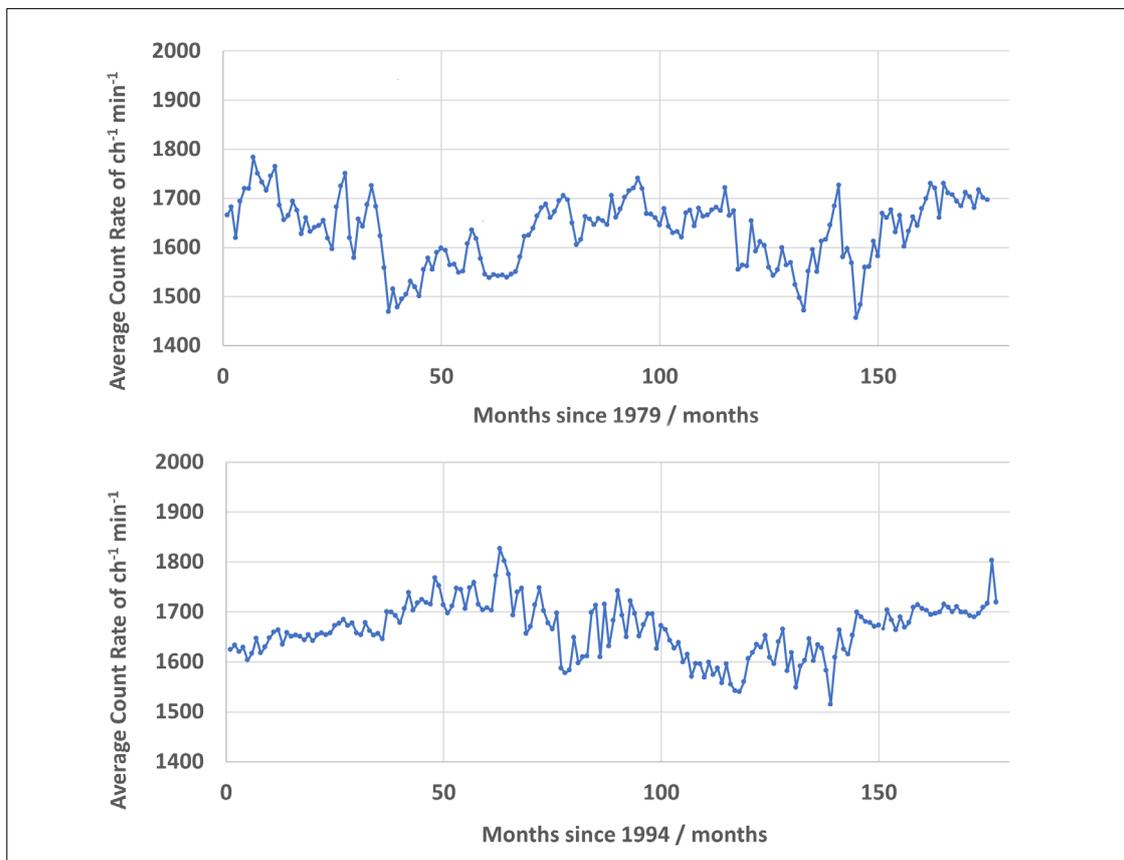


Fig. 3: Two halves of ~29 years data of Calgary NM were used to validate the method.

Upper panel: Count rate time series during the first half with 1st order correction for solar activity.

Lower panel: Count rate time series during the second half with 1st order correction for solar activity.

4. Conclusions

The use of multiple regression to obtain base-line count-rates for neutron monitors appears to offer a convenient way to correct for solar modulation and drift over the long term. Some improvement in accuracy might be achieved if days with larger short-term variations such as GLEs and Forbush decreases, were removed.

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