Solar Magnetic Polarity Effect on Neutron Monitor Count Rates from Latitude Surveys Versus Antarctic Stations

K. Poopakun[*a] W. Nuntiyakul[a] D. Ruffolo[b] P. Evenson[c] J. Peng[d] P. Chuanraksasat[e] M. L. Duldig[f] J. E. Humble[f] S. Oh[g]

[a]Chiang Mai University [b]Mahidol University [c]University of Delaware [d]Polar Research Institute of China [e]NARIT [f]University of Tasmania [g]Chonnam National University

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Introduction

Galactic cosmic rays (GCRs) are high energy particles from outside the solar system arriving at the Earth. When GCRs enter the heliosphere, they encounter a turbulent magnetic field, causing significant variation in their intensity and energy. The influence of the sun on the intensity of GCRs is referred as Solar modulation. The GCR spectrum varies with the sunspot cycle and the solar magnetic cycle. It is clearly seen in Figure 1 that the neutron monitor count rate is related to solar activity with 11-year cycle.

A mobile neutron monitor can record data rapidly through a wide range of geomagnetic cutoffs in a so-called latitude survey [1]. Latitude surveys in previous work [3, 2] show an intersection of the two spectra, called the "crossover." The crossovers can also be seen from the correlation of latitude survey neutron monitor count rates and count rates of fixed neutron monitors such as that at McMurdo station [2]. A regression analysis found a consistent trend with slopes that change when solar magnetic polarity flips, most likely due to a systematic change in the interplanetary diffusion coefficient for cosmic rays.

In recent years the neutron monitor at McMurdo has been moved to the Jang Bogo station, and the mobile neutron monitor has been reconfigured. The series of 13 annual latitude surveys from 1994 to 2007 used by [2] therefore cannot be directly extended. In this work we repeat the analysis using neutron monitor data from the existing neutron monitor station, Mawson, instead of McMurdo station and confirm the crossovers. We also analyze two recent latitude surveys in 2019 and 2020 with a monitor similar to the 3NM64 in the previous surveys, but without the lead producer surrounded the central tube, the so-called "semi-leaded neutron monitor." We present this analysis using both the Mawson and Jang Bogo neutron monitor stations.

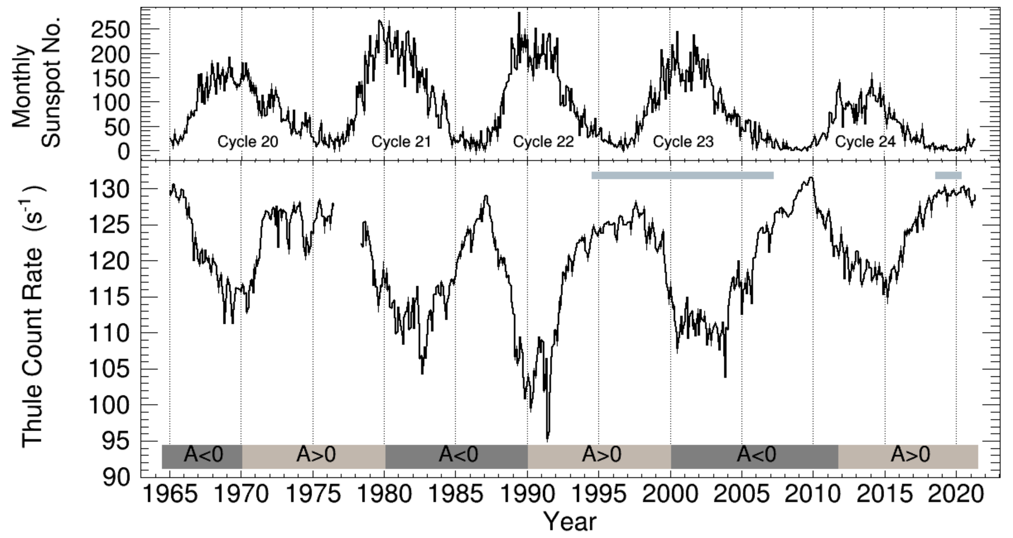

Figure 1. As solar activity rises (top panel, Source: WDC-SILSO Royal Observatory of Belgium, Brussels), the pressure-corrected count rate recorded by the neutron monitor in Thule decreases (bottom panel, Source: Bartol Research Institute, University of Delaware, USA). The solar magnetic polarity reversal can be seen between positive (denoted by $A > 0$) and negative (denoted by $A < 0$). This work presents observations for the periods 1994-2007 and 2018-2020, as indicated by horizontal bars between two panels.

Observation

Mobile neutron monitors

- **Thirteen survey years, 1994–2007** : We use count rate data corrected for pressure but uncorrected for short-term modulation variations with McMurdo count rate. We exclude times of large Forbush decreases >10% documented in [2].
- **Two survey years, 2018–2020** : We use used two standard neutron monitors flanking one lead-free neutron monitor. For the whole survey data in 2018 and only the southbound data in 2019, the count rate data provided in [4]. For additional data, we obtain it from Yakum et al. (in preparation).

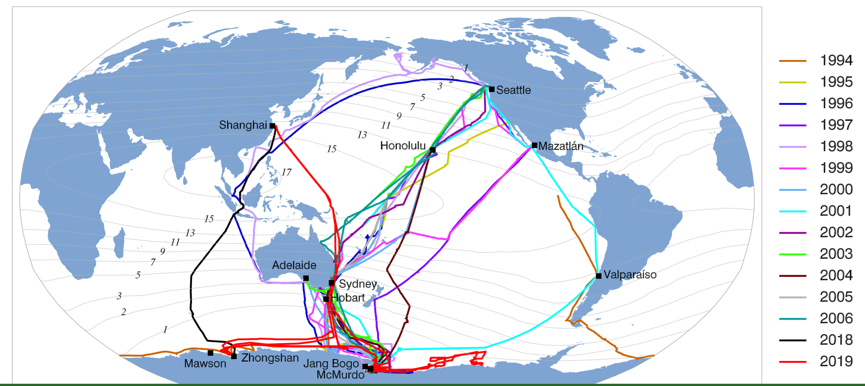

Figure 2. The track of the ship-borne neutron monitor latitude surveys for 1994-2007, and 2018- 2019

Fixed neutron monitor stations

- **Jang Bogo neutron monitor**: The 18-tube NM64 is installed near the cosmic ray lab. The data are available from the NMDB website https://www.nmdb.eu/nest, but several months of frequent missing data in 2020. This yields a small amount of data appearing in Figure 4(d).
- **Mawson neutron monitor**: From 1986 to October 16, 2002, a total of six neutron monitors were placed in the station. After October 17, 2002, the system was upgraded to use 18 counter tubes. Analysis of Mawson data is complicated because of changes in the number of counter tubes. Therefore, we explain some details for Mawson data processing in more detail.
  - **Data cleaning based on ratios of count rates** : From October 17, 2002, the number of counter tubes at Mawson increased from 6 to 18. The data is the sum of the count rates for 6 tubes in the same section. We cleaned the data based on ratios of total count rate for each section.
  - **Mawson normalized with McMurdo** : To study the change between the counting rates obtained from the mobile monitor and the fixed neutron monitor of different stations, we calibrate Mawson count rates with McMurdo count rates because data from 13 survey years has been normalized with McMurdo [2]. Here, we applied a normalization factor of 1.0533 to the uncorrected Mawson count rate (shown in red in Figure 3) from January 1, 2003, until the survey year 2006 ended. Black data points in Figure 3 are the data that we use for analysis throughout this work.

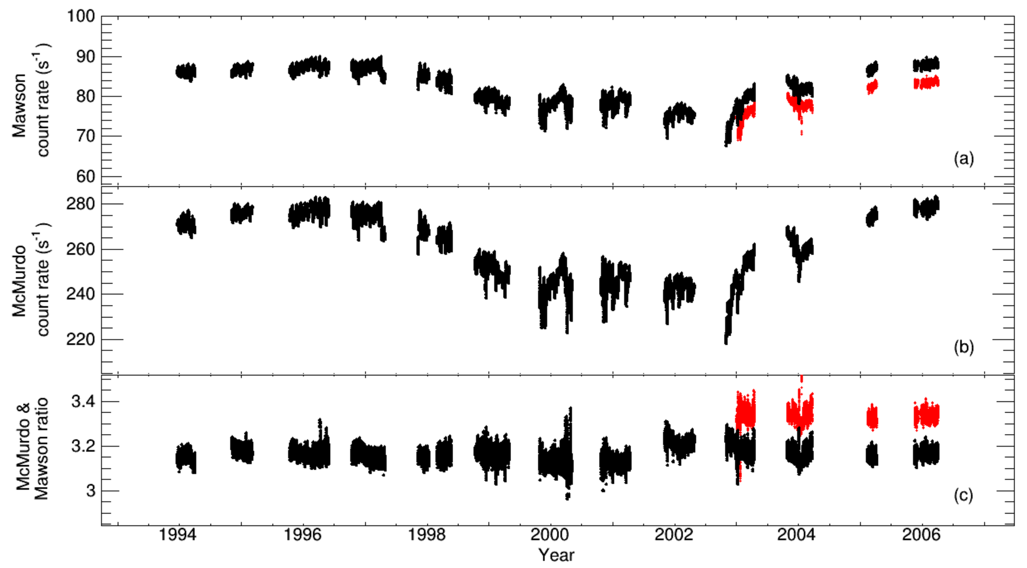

Figure 3. The count rate of 13 survey years from 1994 – 2007 at different fixed neutron monitor stations. (a) Mawson, (b) McMurdo, and (c) McMurdo/Mawson count rate ratio. Black dots indicate the data after normalization. Red dots represent the data before normalization.

Consolidation of latitude survey data to study solar magnetic polarity effect

- **Recent Surveys**
  As there is no lead producer surrounding the central tube in these two surveys, we neglect data of this tube and use only the standard NM64s (T1&T3) flanking the central tube for the analysis. We compare the ship-borne data to the two stationary stations Mawson and Jang Bogo, as the ship traversed close to those stations (see Figure 2). Figure 4 shows the regression of the T1+T3 count rates against the Mawson and Jang Bogo neutron monitor count rates for every third rigidity bin. The dots in Figure 4 indicate the hourly count rates of the neutron monitors. Our results demonstrate that the regression of semi-leaded neutron monitor count rates in survey years 2018–2019 vs. fixed station neutron monitor count rates can also be fitted by a straight line. Because Jang Bogo data are missing at various periods when it coincided with the ship-borne data, we then focus on the only analysis of Mawson data for the present surveys.
- **Earlier Surveys**
  We used 1994–2007 data from [2] corrected for pressure and uncorrected for short-term variation and also removing Forbush decrease events. Mobile monitor count rate data were divided into 1 GV width bins in apparent cutoff rigidity and plotted against the count rate of Mawson neutron monitor, as shown (for every third rigidity bin) in Figure 5 including all the survey years for both solar magnetic polarity states. Figure 5 should be compared with Figure 10 in [2]. The regression for each rigidity bin against Mawson can be fitted by a straight line. We confirm the change in the slope before and after solar polarity reversal in the year 2000.

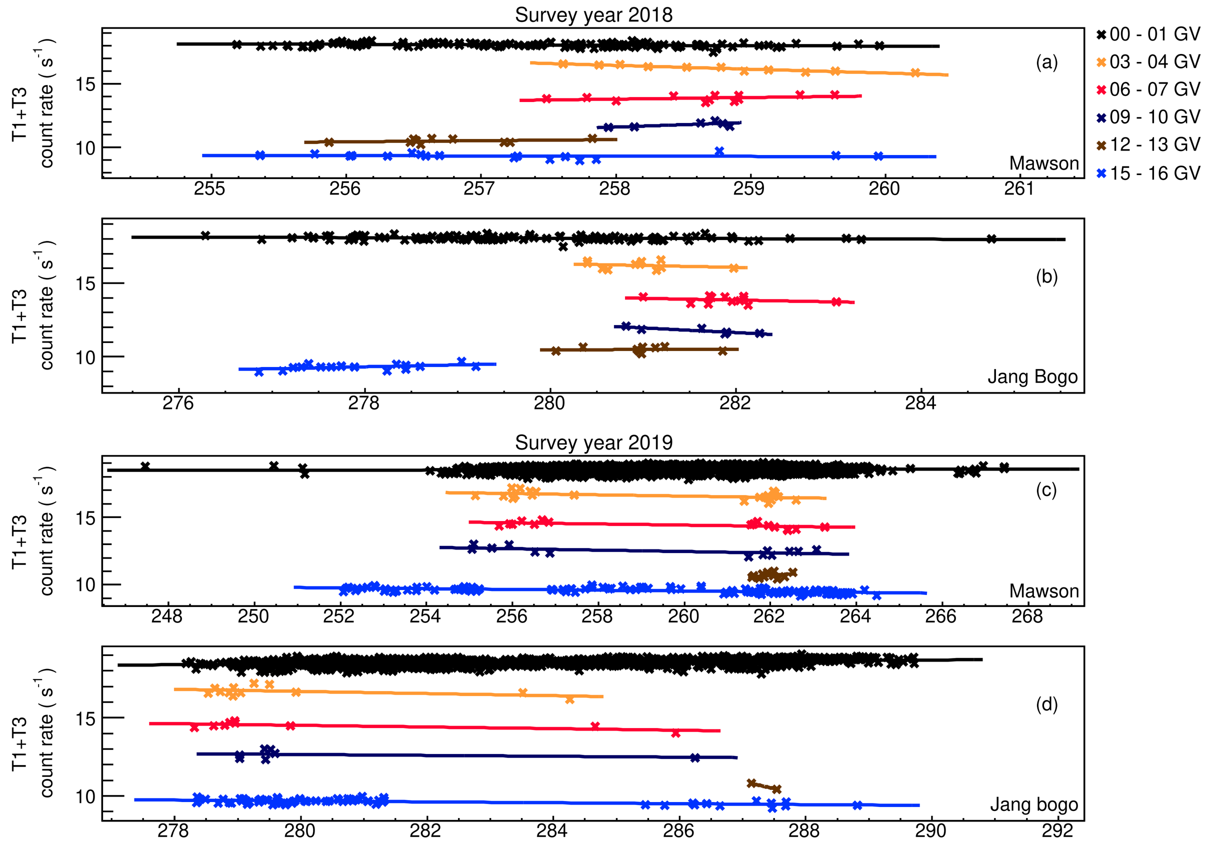

Figure 4. (a)–(b) Linear fits of mobile monitor count rate (s^{-1}) of sum T1 and T3 against Mawson and Jang Bogo hourly count rate (s^{-1}) for the 2018 survey year and (c)–(d) for the 2019 survey year for selected rigidity bins.

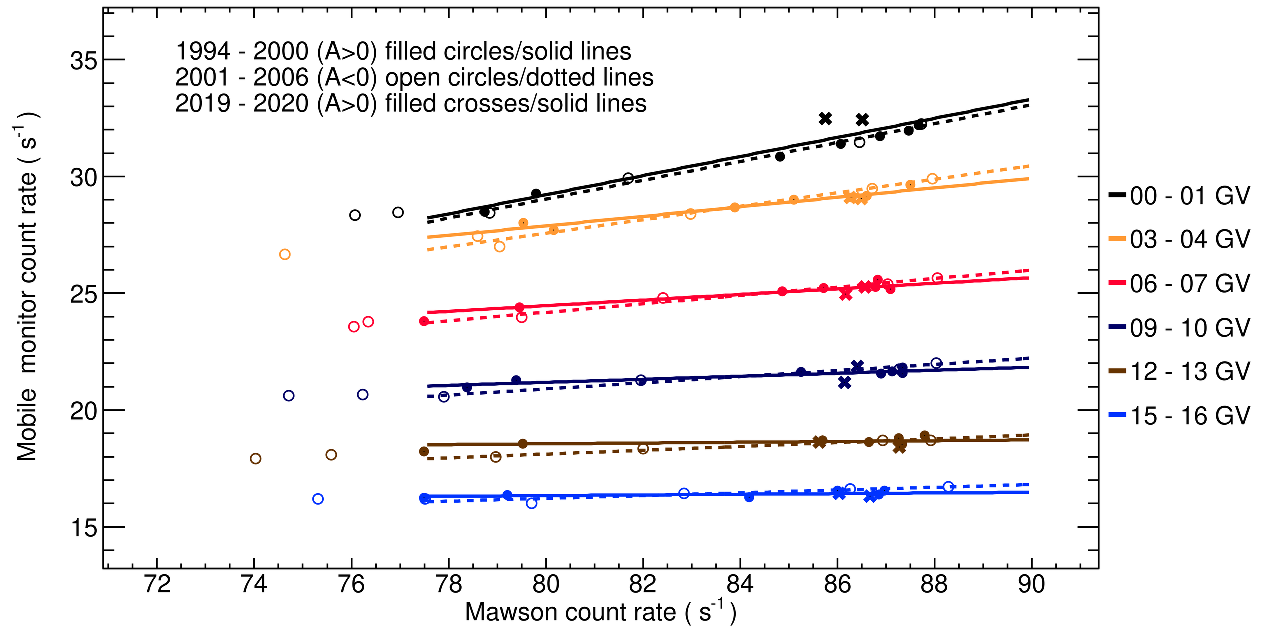

Figure 5. Regression of the mobile neutron monitor count rate in different apparent cutoff rigidity bins against the count rate of Mawson monitor superimposing the data for different solar magnetic polarities.

Result and Discussion

To compare the two tubes in the recent survey years to the 3NM64 in a 13-year survey, we apply a normalization factor of 1.80 for the survey year 2018 and that of 1.75 for the survey year 2019 to T1+T3. We obtain two data points for each rigidity bin which have been added to Figure 5. Our results confirm linear trends between count rates at different geomagnetic cutoff rigidity and changes in slope before and after the polarity reversal in 2000 as an effect of solar magnetic polarity similar to the results shown in [2]. Results from two recent latitude surveys are consistent with the previous conclusions.

Acknowledgments

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