**Seasonal Variation of Cosmic Ray Intensity Observed by the Oulu Neutron Monitor**

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Muons and neutrons are representative secondary particles that are generated by interactions between primary cosmic ray particles (mostly protons) and the nuclei of atmospheric gas compounds. Previous studies reported that muons experience seasonal variations because of the meteorological effects of temperature. The intensity of neutrons has a typical modulation with various periods and reasons, such as diurnal and solar variation or transient events.

**Keywords**: cosmic ray, Oulu neutron monitor, seasonal variation, grand mean, transformation

**1. INTRODUCTION**

Muons and neutrons are produced by interactions between primary cosmic ray particles and the nuclei of atmospheric gas compounds. They can then be detected on the ground or underground. Interactions with the atmosphere are important factors determining the intensity of muons and neutrons. The flux of neutrons as the secondary cosmic ray particles can be modulated by solar activity and solar eruptions. They also experience diurnal variations by the local anisotropy of cosmic ray intensity during the Earth’s rotation (Oh & Yi 2006, Oh et al. 2010, Park et al. 2018).

**2. DATA AND METHOD**

**2.1 Data preparation**

The Oulu neutron monitor has been collecting the cosmic ray intensity data since it started operation in 1964. The Oulu station also has been providing researchers with collected data on different time scales, i.e., hourly, daily, monthly, and yearly data. From the Oulu station, the daily mean data were downloaded and analyzed to remove the diurnal variation of the data. Before 1974, the detector was located in a building with a flat roof where snow could accumulate during winter (Tanskanen 1968).

To that end, two different transformations were first considered: transformation with respect to (w.r.t) the grand mean and transformation w.r.t the yearly mean. More specifically, the transformation w.r.t grand mean is defined as follows:

,

where is cosmic ray intensity of day of year , , and is the grand mean of all data. Similarly, transformation w.r.t the yearly mean is defined as

,

where is the mean of the data of year , i.e., .

**2.2 Data analysis**

Although the distribution of cosmic rays is assumed to be isotropic, cosmic ray particles experience different solar activity, which varies with the sunspot numbers. This is because of the magnitude of the solar magnetic field, which displays the solar cyclic variation of the cosmic ray intensity at the Oulu neutron monitor, as shown in Fig. 1. Fig. 1 shows the monthly mean data from April 1964 to December 2019.



Fig. 1. Solar cyclic variation of cosmic ray intensity at Oulu neutron monitor

**3. RESULTS**

As mentioned in Section 2.1, the cosmic ray intensities during January 1974-December 2019 were transformed in two different ways: (a) transformed w.r.t. the grand mean and (b) transformed w.r.t the yearly mean. After the transformation, data were collected on the same day. Each day consisted of approximately 46 observations, and the mean or median was calculated. Fig. 3 shows the mean-based (in black) and median-based (in pink) profiles.





Fig. 3. Profiles of cosmic ray intensity normalized to all data (a) and normalized within one year (b).

Table 1. Results of the Cox and Stuart trend test for the smoothed profiles in Fig. 3.  
(No vertical lines in the table)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | w.r.t the grand mean | | w.r.t the yearly mean | |
| profile | Mean | Median | Mean | Median |
| p-value |  | 0.0001241 |  |  |

**4. SUMMARY AND DISCUSSION**

In contrast to previous studies that examined the seasonal variations due to terrestrial factors, such as the temperature effect, this study examined the seasonal variation by extraterrestrial factors, such as the position of the Earth in the orbit of revolution. This study examined the daily data at the Oulu neutron monitor from January 1974 to December 2019. To eliminate the solar cyclic variations, the profile of cosmic ray intensity for 365 days was calculated using two different transformations w.r.t the grand mean and w.r.t the yearly mean.

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