The Effect of Coronal Mass Ejections on Cosmic Ray Muon Flux

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Abstract

This study investigates the effects of coronal mass ejections (CMEs) on cosmic ray muon flux using QuarkNet detectors. Our analysis characterizes the flux change from time of onset to recovery of the CME event of May 2024. We compare the atmospheric-pressure corrected cosmic ray flux with disturbances of the geomagnetic field. Results show the structure of flux change during a CME event.

Motivation

This study characterizes the Forbush decrease that follows a coronal mass ejection (CME). Knowing that CMEs impact cosmic ray flux, we studied the CME event of May 10, 2024. We investigate time of onset, duration of drop, percentage of drop, and duration of recovery.

How do fluctuating values of the magnetic Kp-index affect the change in muon flux? What is the minimum magnetic disturbance needed to observe the Forbush decrease?

Hypothesis

QuarkNet detectors characterize the Forbush decrease when the Kp-index is greater than 6.

Equipment

Data were collected from various Cosmic Ray Muon Detectors, with the majority in Illinois. Detectors employed a variety of geometric arrangements.

Methodology

A search was conducted for all QuarkNet detectors surrounding the May 2024 CME event. Detectors in the database with sufficient and reliable data were selected for further study. The selection criteria included the number of days data were collected and checking limits in the blessing charts in eLab.

The selected data were corrected for barometric pressure changes[1]. When comparing the uncorrected data (Figure 1) with the corrected data (Figure 2), a clearer pattern of the CME event is revealed. Further analysis in our experiment utilizes the corrected data.

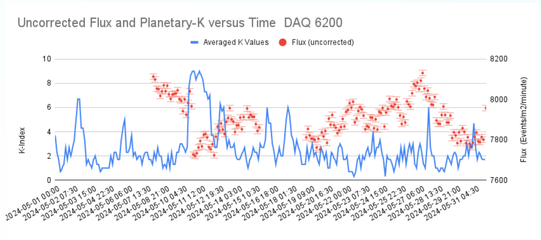

Figure 1
Graph of raw data before pressure corrections

Results

# DAQ	Top Average (events/m²/minute)	Bottom Average (events/m²/minute)	Avg flux dur. onset (events/m²/minute)	Total drop (events/m²/minute)	% Decrease	% Error	Recovery time (days)
6119	574	564	569	10	1.73	4.17	14
6200	7914	7604	7759	310	3.91	1.12	18
6400	3593	3466	3529	127	3.52	1.67	18
6429	546	523	535	23	4.14	4.28	13
6620	7652	7398	7525	254	3.32	1.14	12
6678	8184	7920	8052	264	3.23	1.11	15
6899	8612	8276	8444	336	3.90	1.08	10
6994	3491	3332	3412	159	4.56	1.69	insufficient data

Table 1
Results showing the structure of onset and recovery of a CME event

To determine characterizations of the Forbush decrease from each corrected Flux and Planetary-K versus Time graph, flux values of Top Average and Bottom Average are determined as shown. Averaging the flux values immediately before the onset of the CME yields the Top Average, while averaging flux values immediately after the onset time gives the Bottom Average. In order to gain a broader understanding of the behavior of muons during onset, we determine the Average Flux during onset, which is the mean of the Top and Bottom Averages (Table 1, column 4).

The changes in muon counts before and after the onset time are represented in column five as the difference between the Top and Bottom Average. We identify the percent decrease of drop and it ranged from 1.7% to 4.6% (Table 1, column 6), using the formula:

$$Percent\ decrease = \left(\frac{Taverage - Baverage}{Taverage}\right) * 100 \quad (1)$$

This was for a Kp-index of 9.

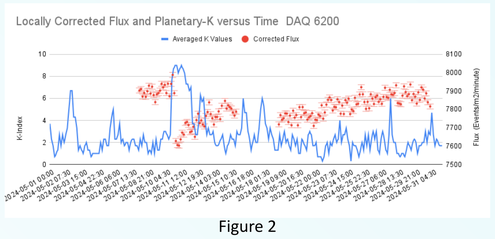

Figure 2
The cosmic ray flux compared with the Kp-index; small error bars due to large sample size

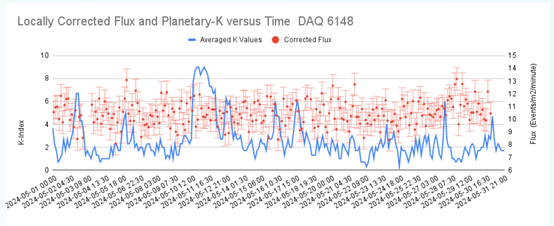

Figure 3
Flux data compared with the Kp-index, displaying large error bars due to small sample size

There are statistical errors due to sample size. Percent error is calculated using the formula and shown in column seven:

$$Percent\ error = \left(\frac{1}{\sqrt{Top\ Average}}\right) * 100 \quad (2)$$

The Forbush decrease of flux was an average of 3.14%. The recovery time is the duration from onset until the flux returns to pre-event levels. For the May 10th event, the recovery time was about 14 days. Smaller geomagnetic storms of Kp-index 6 on May 18 - 20th extend the flux recovery time (Figure 4). There are indications that Kp-indeces as low as 4 show this effect.

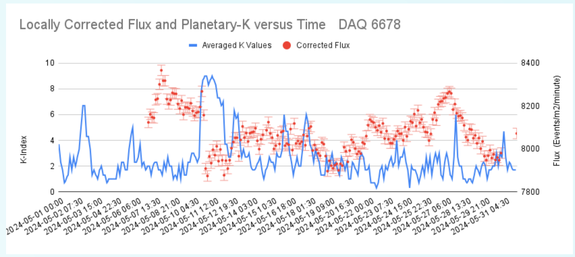

Figure 4
Flux and Kp-index levels showing the influence of smaller geomagnetic storms following the CME

Graphs which included error bars larger than the signal itself were omitted from the above analysis, since the data derived from the graph would not reach the desired level of specificity. Figure 2 depicts the ideal size of error bars, while Figure 3 depicts a situation where analysis of Forbush decrease will be unreliable due to the large error bars obscuring the structure of flux recovery.

Conclusion

As values of the Kp-index increased above 4, QuarkNet detectors displayed a decrease of the cosmic ray muon flux. The decreases were typically averaged 3% and statistical errors were 1%. We are confident of measuring the Fobursh decrease when the Kp-index is greater than 4. For further research, we need to conduct more processing for lower Kp-indeces.

References

[1]Zacks, Maya et. al., *Removing the Effect of Barometric Pressure on Muon Flux to Isolate the Coronal Mass Ejection,* AAPT Winter Meeting, POS-SAT-A105, 1/18/2025

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