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Thunderstorm-Induced Muon Events: Insights from the GRAPES-3 Experiment in Ooty

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Introduction

The GRAPES-3 experimental site is located in Ooty. A large-area tracking muon telescope is used to measure the muon content in cosmic ray showers. The telescope consists of 4 super-modules, each containing 4 modules. Individual modules comprise 4 layers of 58 PRCs, with alternate layers aligned in mutually orthogonal directions, having a sensitive area of 35 square meters, making a total of 560 square meters for the telescope [1, 2].

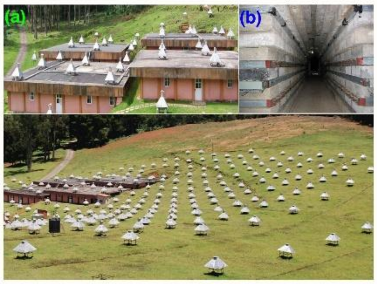

Figure 1: Array showing the four super-modules housing the muon detectors on the left. Inset: (a) A closer view of the super-modules hosting all modules. (b) Inside view showing two modules; the others are further inside [1].

The 4-layer configuration of the muon module allows the reconstruction of each muon tracks in two mutually orthogonal planes. The vertical separation of the two PRC layers in the same projection plane is 50 cm, allowing for the measurement of the muon track direction with an accuracy of less than 4° in each projected plane [3, 4, 5].

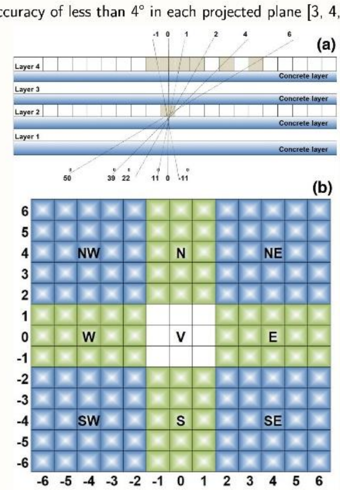

Figure 2: (a) Reconstruction of muon directions in a single projection plane, (b) A schematic of 169 muon directions subsequently combined into nine coarse directions. [2]

The thunderstorm-induced muon events (TIMEs) are observed when strong electric fields in thunderstorms modulate muon acceleration, resulting in an altered count rate at the observational level. These TIMEs are event-specific and characterized by direction, duration, and intensity [1].

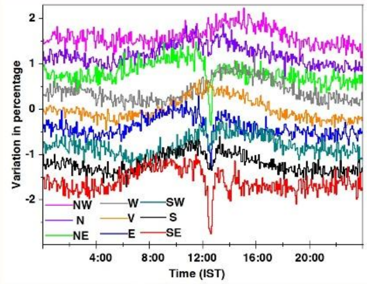

Figure 3: Observation of a strong TIME showing the variation in muon intensity in nine coarser directional beans. Change in the vertical direction is shown in orange. For the other directions, a fixed value in multiples of 0.4 has been added or subtracted for better data visualization [1].

The atmospheric electric field variation is measured using four electric field monitors (Boltek model EFM-100), installed in and around Ooty as shown in Figure 4. We report the variations of the near-surface electric field and meteorological parameters during both fair weather and disturbed weather for 2021 and 2022 [6].

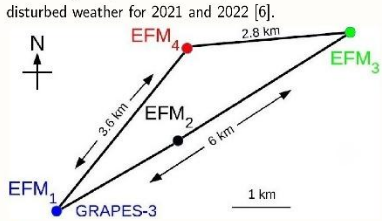

Figure 4: Arrangement of four Electric Field Mills. The maximum distance of 6 km between EFM1 and EFM3 [6].

The fair-weather criteria are highly subjective and vary from place to place, determined based on atmospheric conditions. During the first two months of 2022, all days experienced fair weather and showed an interesting pattern as depicted in Figure 5. The large-scale electric field changes remained constant at 105 for both years but were found to vary with the seasons.

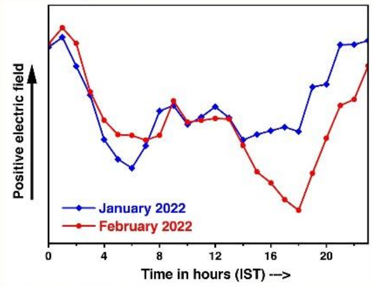

Figure 5: Observed fairweather electric field at GRAPES-3 site during two months of 2022 with undisturbed weather.

Results & Discussions

Figure 6 shows the telescopic view of an event observed in June 2022. During the period of 14:32–15:00 IST, there is an apparent decrease followed by its disappearance, which is visible as time progresses from (i) to (viii).

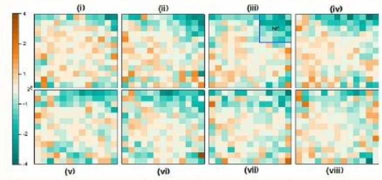

Figure 6: A telescopic view of muon intensity variation of a TIME during a 28-min thunderstorm starting from 14:32 IST with 4-min intervals is depicted. The maximum decrease in intensity observed at 14:40 IST, highlighted by the dark boundary in the N–E direction in (iii). The left vertical bar indicates the color coded percent variation [2].

In a similar manner, in 2021, 46 TIMEs were detected, compared to 54 in the subsequent year, as shown in Figure 7. The majority of TIMEs occur in the spring and autumn seasons, with fewer in the winter.

Observed Thunderstorm-induced Muon Events

Year	Spring (Mar-May)	Summer (Jun-Aug)	Autumn (Sep-Nov)	Winter (Dec-Feb)	Yearly Total
2021	19	8	17	2	46
2022	22	18	11	3	54
Seasonal Total	41	26	28	5	100

Events observed due to large-scale electric field changes

Year	Spring (Mar-May)	Summer (Jun-Aug)	Autumn (Sep-Nov)	Winter (Dec-Feb)	Yearly Total
2021	38	25	34	8	105
2022	43	36	23	3	105
Seasonal Total	81	61	57	11	210

Figure 7: Seasonal variation of TIMEs and EFM events during two continuous years of 2021 and 2022.

Summary and further scope

This study comprehensively analyzes statistically significant TIMEs observed during 2021 and 2022, and compares them with the observed large-scale electric field variation events. It is the first-ever report to observe a strong correlation between TIMEs variation and the EFM data for such a long period. The study outcome leads us to remain cautiously optimistic about the plausible potential for a new discipline that explores the interplay between astroparticle physics and atmospheric sciences.

References

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