

## Preliminary Investigation of Atmospheric Muon Flux Detection in Sri Lanka and its Potential for Weather Prediction

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### 1. ABSTRACT

This study presents a preliminary investigation of atmospheric muon flux measurements in Sri Lanka using two muon scintillation detectors at the Department of Physics, University of Colombo. The detectors are from the Georgia State University ‘global Low-Cost Observation of the dynamic changes in the Space weather and Terrestrial weather’ (gLOWCOST) collaboration. Direct muon counts from the three scintillator plates and muon coincidence counts between any two plates are utilized to investigate the sensitivity of the muon detectors with respect to ambient temperature, as well as the relationship between muon flux and atmospheric parameters such as air temperature, air pressure, and relative humidity. One-minute data obtained from the detectors were used in the former investigation, while hourly averaged count data were used in the latter investigation. A significant dependence on ambient temperature was observed in Detector 1, whereas the improved Detector 2 showed no significant dependence. A negative correlation was observed between muon flux and air pressure with a gradient of  $-0.188 \text{ hPa}^{-1}$ . A smaller positive correlation was observed with air temperature with a gradient of  $0.064 \text{ }^{\circ}\text{C}^{-1}$ . The observed trends and relationships are consistent with existing literature for non-equatorial regions and proposed theories for equatorial regions. Therefore, this study concludes that, when operated under varying weather conditions, muon flux measurements have the potential to be used as indicators of weather-related changes.

**Key words:** Muon flux, gLOWCOST, ambient temperature, atmospheric parameters

### 2. INTRODUCTION

Cosmic rays are high-energy particles from outer space that predominantly consist of protons and helium nuclei, with smaller amounts of heavy nuclei. They are of two types: *primary cosmic rays*, which are particles that travel through space and strike the Earth’s atmosphere, and *secondary cosmic rays*, which are produced when primary cosmic rays collide with nuclei in the Earth’s atmosphere. The hadronic shower that is then created consists of hadrons such as protons, pions, and kaons. These pions decay into muons that travel towards the Earth’s surface.

Although the lifetime of a muon is only  $2.2 \mu\text{s}$ , due to time dilation in the rest frame of the muon, it travels further than expected and can be detected at the Earth's surface [1], [2].

The muon scintillation detectors of Georgia State University's gLOWCOST collaboration are ground-based detectors that measure the muon flux at the Earth's surface. Among these detectors, which are distributed worldwide in locations such as the United States, Japan, Singapore, Sweden, and Sri Lanka, this study focuses on the two detectors located at the Department of Physics, University of Colombo, Sri Lanka. Detector 1 was operationalized in October 2023, while Detector 2 was operationalized in July 2024 (Figure 1).

According to existing literature and proposed theories, the muon flux varies with terrestrial atmospheric parameters such as air temperature, air pressure, and relative humidity [3], [4], [5], [6], [7]. Studies have been conducted in many geographical locations; however, there is a lack of such research in equatorial regions such as Sri Lanka. Furthermore, the silicon photo multiplier's output is known to vary with ambient temperature [8].

Thus, the focus of this study is twofold. The first is to study the performance of the detectors with respect to ambient temperature, and the second is to observe trends in the muon flux in relation to terrestrial atmospheric parameters such as air temperature, air pressure, and relative humidity in Colombo.

### 3. METHODOLOGY

Each gLOWCOST muon scintillation detector consists of three plastic scintillator plates, wavelength-shifting (WLS) fibers, and silicon photo multipliers (SiPM). The number of muons that pass through each plate is recorded over a 1-minute period. The principle of coincidence counts is utilized for detection. A muon is considered to have passed through the detector only if it is detected by two scintillator plates. The coincidence counts between the top and middle plates (coincidence\_0\_1), between the middle and bottom plates (coincidence\_1\_2), and between the top and bottom plates (coincidence\_0\_2) are recorded each minute.

Each of the three plastic scintillator plates has the dimensions of  $(20 \times 20 \times 1) \text{ cm}^3$ , while the perpendicular distance between two scintillator plates is 13 cm. The SiPM mounted at the corner of the plate records the scintillation light that is created when a muon passes through the plate. The voltage of the SiPM is supplied by a small high voltage unit integrated to the main data acquisition and coincidence processing unit mounted on the Raspberry Pi [9].

In both detectors 1 and 2 shown in figure 1, the coincidence count combinations are recorded as stated previously. In addition, Detector 1 records the direct counts individually from each scintillator plate, which are ch0 (top plate), ch1 (middle plate), and ch2 (bottom plate). Detector 2, however, provides only the direct count from the top scintillator plate due to limitations in the Field-Programmable Gate Array (FPGA) output, which was used for coincidence processing. Further, the ambient temperature, air temperature, air pressure, and relative humidity needed for the study were measured every minute using two BME280 sensors.

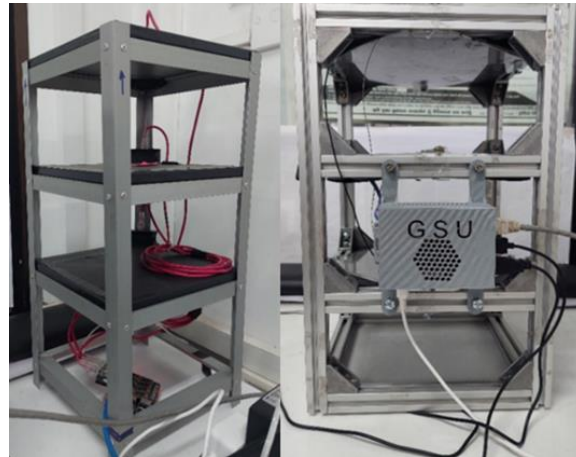


Figure 1: The two muon scintillation detectors in Colombo. Left: Detector 1. Right: Detector 2.

#### 4. RESULTS AND DISCUSSION

The muon flux coincidence counts between the scintillator plates are recorded every minute. However, to improve the signal to noise ratio, the muon flux coincidence counts are taken as an average over a five minute or one hour interval (figure 2). Further, while the coincidence counts can be directly plotted, the muon flux changes are easier to visualize when plotted as a percentage change in the coincidence count with respect to the mean coincidence count.

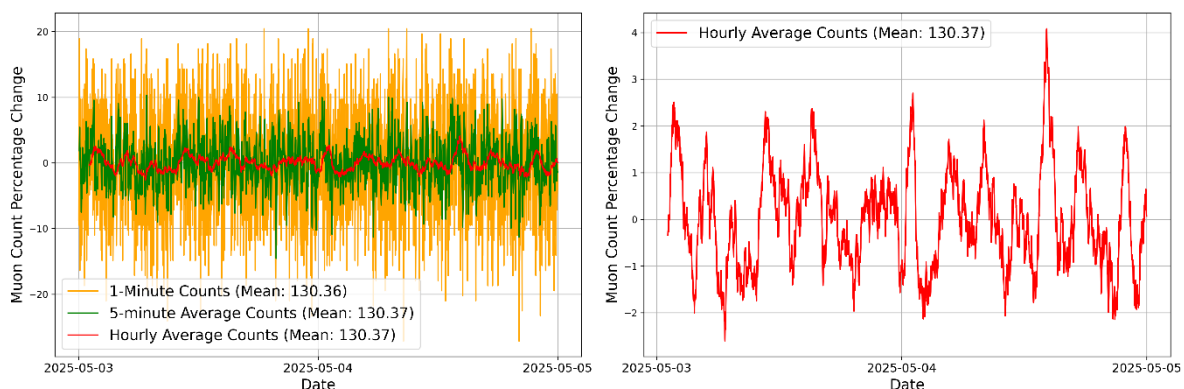


Figure 2: Left: Muon percentage change of the Detector 2 coincidence count between the middle and bottom scintillator plates (one-minute, five-minute average, hourly average) with respect to the mean value for the period from May 3, 2025 to May 4, 2025. Right: The hourly average muon percentage change plotted separately for the same period.

##### 4.1 Ambient Temperature Dependence of the Detector

In Detector 1, a significant variation in the count rates with ambient temperature was observed. However, Detector 2, which is the improved version of Detector 1, does not show significant variation with ambient temperature. For this analysis, one-minute direct channel (plate) muon counts and muon coincidence counts were utilized, as depicted in figures 3 and 4 respectively.

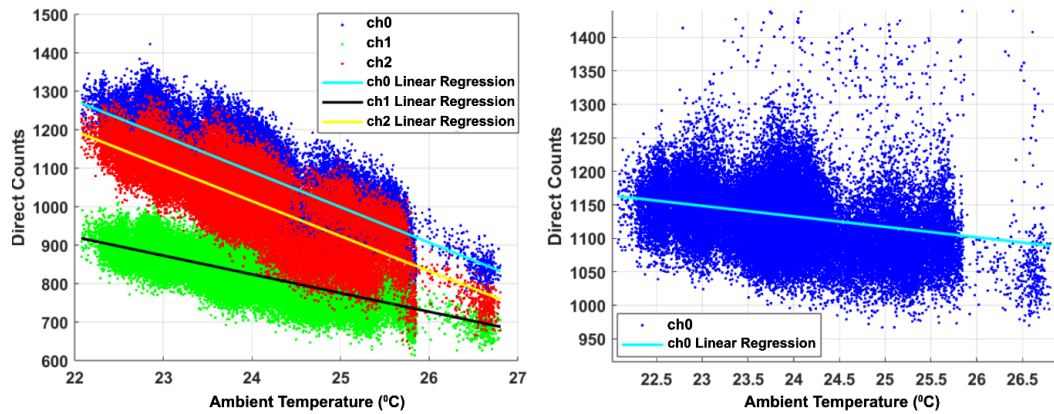


Figure 3: Left: Detector 1 all channels (scintillation plates) direct counts variation with the ambient temperature. Right: Detector 2 channel 0 (top plate) direct muon count variation with the ambient temperature.

The linear correlation coefficient for Detector 1 is high, with  $R^2$  values of 0.9726 for channel 0 (top plate), 0.9270 for channel 1 (middle plate), and 0.9681 for channel 2 (bottom plate), where  $R^2$  represents the proportion of variance explained by the model. In contrast, Detector 2 shows a very low linear correlation coefficient, with an  $R^2$  value of 0.0005 for channel 0.

In Detector 1, all channel direct counts show a strong linear relationship with ambient temperature. From the perspective of the SiPMs, since it has a temperature dependence, a correction can be done to it by varying the SiPM bias voltage.

These observations indicate that gain variation of the SiPM is the primary factor responsible for the decrease in count rates with increasing ambient temperature. Based on SiPM datasheets and technical notes, this gain variation can be compensated by appropriately adjusting the bias voltage as a function of temperature [8].

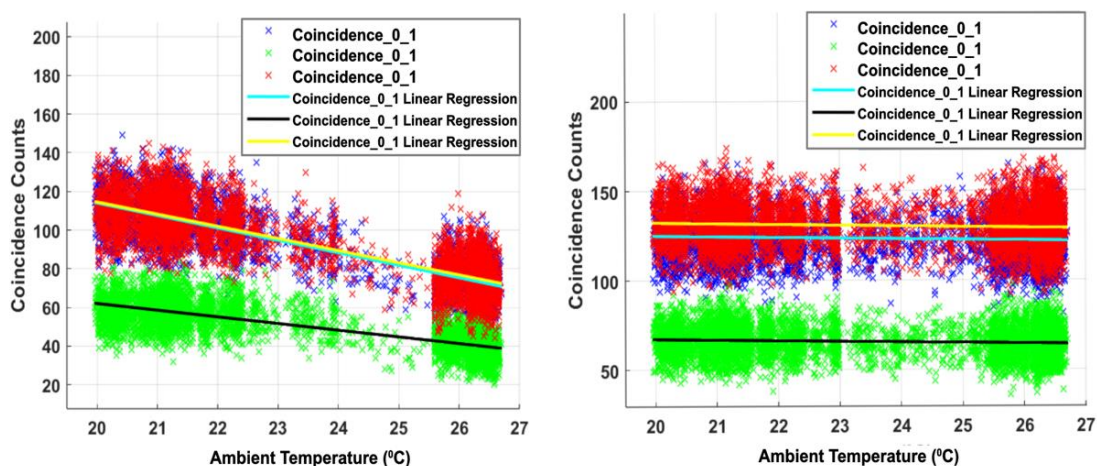


Figure 4: Variation of muon coincidence counts between scintillation plates (top and middle, top and bottom, middle and bottom) with ambient temperature. Left: Colombo Detector 1. Right: Colombo Detector 2.

Once again, the linear correlation coefficient for Detector 1 is high, with  $R^2$  values of 0.7457 for the coincidence between the top and middle plates, 0.6042 for between the top and bottom plates, and 0.7265 for between the middle and bottom plates. In contrast, Detector 2 again shows a very low linear correlation coefficient, with  $R^2$  values of 0.0091, 0.0154, and 0.0108 respectively for the three coincidence counts.

The linear relationship between the coincidence counts and the ambient temperature in Detector 2 is weak and the  $R^2$  values are low. Thus, Detector 2 can be utilized for muon flux investigations without performing ambient temperature correction.

#### 4.2 Variation of Muon Flux with Atmospheric Parameters

This section focuses on whether there is a noticeable effect on the muon flux in Colombo, Sri Lanka by the terrestrial atmospheric parameters. Fast Fourier Transforms (FFT) were performed to the hourly-averaged muon coincidence count between the middle and bottom plates (coincidence\_1\_2), the air temperature, air pressure and relative humidity values for the period from January 1, 2025 to December 28, 2025, with the focus on the number of cycles per day (figure 5). Detector 2 was utilized for terrestrial atmospheric parameter analysis.

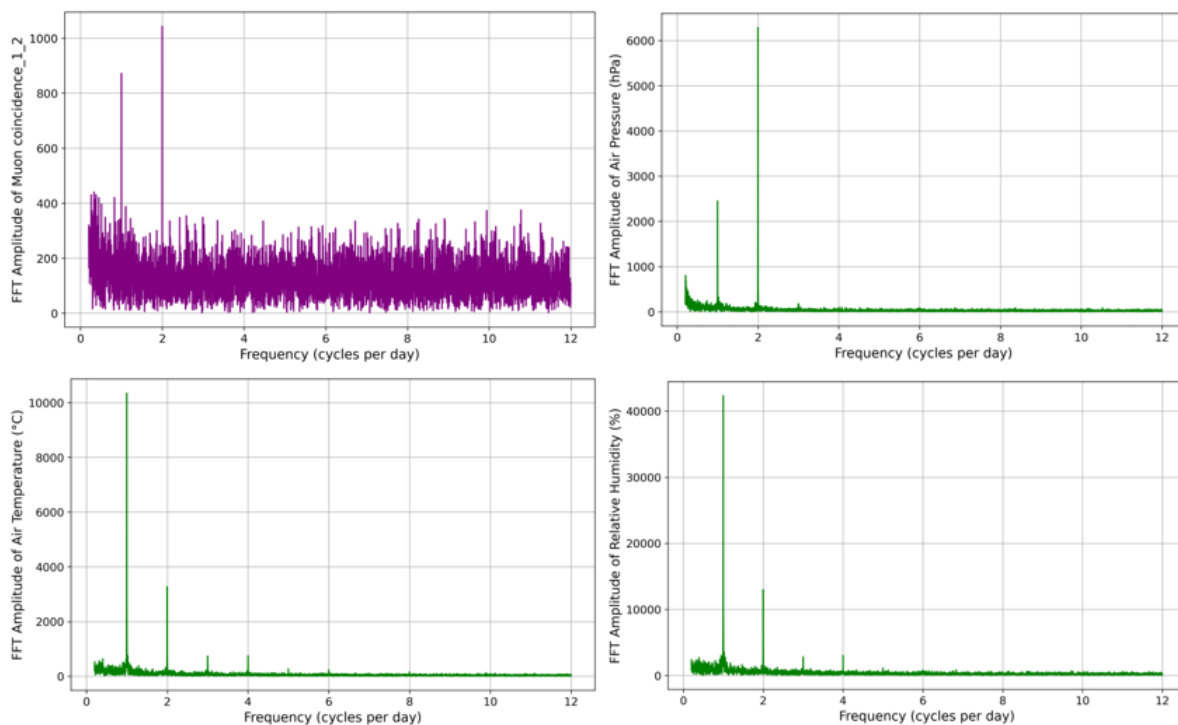


Figure 5: FFT performed on the hourly-averaged muon coincidence\_1\_2 (top-left), air pressure (top-right), air temperature (bottom-left), and relative humidity (bottom-right) for the time period from January 1, 2025 to December 28, 2025.

The FFT for air pressure yielded a dominant peak at two cycles/day, while that for temperature and relative humidity yielded a dominant peak at one cycle/day. The observation for air pressure is consistent with the semidiurnal barometric cycle that causes two 12-hour cycles/day.

This occurs because the atmosphere has a natural resonant semidiurnal mode, which is excited by solar heating. Near the Equator, warm convective currents further strengthen this cycle, contributing to the pronounced semidiurnal variations observed here [10], [11].

The FFT for the muon coincidence count between the middle and bottom plates yielded dominant peaks at one and two cycles/day. The other peak at four cycles/day could be due to harmonics, while the subsequent smaller peaks appear to be due to noise. The dominant peaks in the muon coincidence count could be explained using the three atmospheric parameters considered in this study.

The coincidence count of Detector 2 was visualized in relation to air temperature and air pressure for the period from May 17, 2025 to November 17, 2025. Binned hourly-averaged coincidence counts were considered for atmospheric parameter bins of size 0.2 units. Below are the plots for muon coincidence\_1\_2.

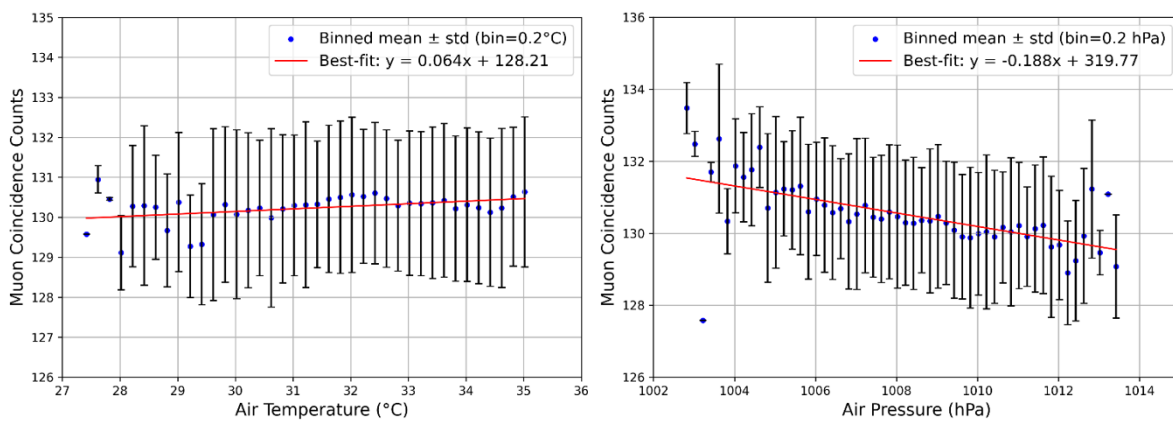


Figure 6: Muon flux coincidence counts of Detector 2 between the middle and bottom scintillation plates in relation to air temperature (left) and air pressure (right) for the period from May 17, 2025 to November 17, 2025, along with the best fit line and atmospheric coefficients in the form of the gradient.

A negative effect of  $-0.188 \text{ hPa}^{-1}$  was observed for the muon count with air pressure in Colombo. According to current literature, an increase in air pressure would cause an increase in the atmosphere for muons to pass through, which would cause an increase in the mass absorption of cosmic rays in air, which would then decrease the number of muons reaching the Earth's surface. This creates a negative effect with air pressure [4], [6]. Thus, the pressure gradient obtained in Colombo is comparable to those obtained in the non-equatorial regions considered in literature.

A positive effect of  $0.064 \text{ }^{\circ}\text{C}^{-1}$  was observed for the muon count with air temperature. This too can be explained by current literature, even though experimental observations are lacking in equatorial regions. An increase in air temperature could have either a positive effect or a negative effect on muon counts. When the atmosphere expands, on one hand, it would cause the muon production region to rise higher in the atmosphere, which would then cause more muons to decay before reaching the ground level. Thus, fewer muons would be detected,

causing a negative effect with temperature. On the other hand, the expanding atmosphere would result in decreasing air density, making pions less likely to collide or be absorbed before they decay. This would cause more pions to decay into muons. Thus, more muons would be detected at the ground level. This is the positive effect with temperature [4], [5], [6], [7].

Colombo is an equatorial region. Near the equator, the incident primary rays are more energetic, therefore positive effect would dominate, while further away from the equator, the temperature coefficient should get increasingly negative. The latter has been observed in current literature. The high geomagnetic cutoff rigidity of 17.694 GV at Sri Lanka is reason for this expectation [3], [12].

## 5. CONCLUSION

This preliminary study investigates the sensitivity of the muon detectors with respect to ambient temperature and the variation of atmospheric muon flux measurements with terrestrial atmospheric parameters in two muon gLOWCOST muon detectors installed at the Department of Physics, University of Colombo, Sri Lanka.

Unlike Detector 1, Detector 2, which is its improved version, showed no significant dependence with ambient temperature for both the direct channel counts and the coincidence counts. The muon flux of Detector 2 reflects the well-known semidiurnal barometric variation cycle. Consistent with current literature for non-equatorial regions and proposed theories for equatorial regions, an anti-correlation with air pressure and a correlation with air temperature were observed for the muon coincidence count of Detector 2.

Future studies include the analysis of muon flux with space weather effects like solar flares and geomagnetic storms, the analysis of muon flux with other terrestrial atmospheric parameters like dew point and wind direction, and the observation of the magnetic east west asymmetry of the muon flux by varying the zenith angle.

## 6. ACKNOWLEDGEMENT

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