Periodic Variations in Muon Flux at Project GRAND

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Abstract: GRAND consists of 64 proportional wire chamber detector stations located near the University of Notre Dame and has been used to detect muons since 1995. In this study, 117 days of data has been analyzed to investigate the dynamics of the daily mean variation in cosmic ray flux over the course of a season. This study used GRAND single track muon flux data from 21 July 2007 to 8 January 2008 which were corrected for both temperature and pressure. Fourier transforms and other techniques were used to identify periodic trends in the data sets. Also a sliding FFT was used to investigate the changes of those trends over the course of the collection period. The power spectra revealed significant one and two cycle per day variations which also changed in relative amplitude and phase significantly over this period. This analysis reveals significant seasonal trends in muon flux.

Keywords: Cosmic ray, Fourier transform, Periodic trends, Seasonal variation, Diurnal variation, Oscillations

1 Introduction

Many physical processes both in the atmosphere and in space produce periodic phenomena in surface muon flux. These periodic variations can be used to infer how cosmic rays and their secondary particles travel through the solar system and Earth's atmosphere. The effect of atmospheric variations on cosmic rays and muons has been well studied allowing for these much larger effects to be eliminated so that variations due to non atmospheric and climatic factors can be investigated. Most of these observed periodic variations are attributed to Earth's relative motion in the Interplanetary Magnetic Field (IMF) [3] which produces known short term variations at 1 and 2 cycles per day [4] and longer period cycles corresponding to solar rotation and sun spot cycle [5]. This analysis is largely concerned with detecting and observing variations in the 1 and 2 cycle per day Daily Mean Variation (DMV) via the Project GRAND muon array at the University of Notre Dame.

In this study data were collected for 117 days in 2007 corresponding to one of the longest periods during which the detector was continuously operating. The data set was then corrected for atmospheric effects and variations in the sensitivity of the detector over that time period to eliminate other induced periodicities. The whole data set was then Fourier analyzed to isolate strong periodic trends such as the 1 and 2 cycle per day variation and then subdivided into overlapping 57 day sections to investigate the evolution of those periodic variations over the full time period. This analysis reveals significant changes in both the phase and the amplitude of both the 1 and 2 cycle per day trends.

2 Background

Project GRAND is an array of 64 detector stations located north of the University of Notre Dame at 41.7^{o} N and 86.2^{o} W at an altitude of 220 m above sea level. Two experiments are run simultaneously at the array: the tracking of low energy single muon events and the detection of high energy air showers. The single track muon experiment is increasingly sensitive to primary energies >10 GeV with a median value of 50 GeV for vertical tracks. Each station contains four proportional wire chamber (PWC) plane pairs. These eight 1.29 m^2 PWC planes yield a total active area of 82 m^2. Each of the four chambers in a detector contains a horizontal plane of wires running north-south and another plane of wires running east-west. When a charged particle passes through the chamber, it leaves a trail of ions which accelerate toward the closest signal wire. As they gain energy, they collide with more gas molecules and release more charged particles in a process known as gas amplification which further increases the charge collected on the signal wire resulting in a small current. By identifying the hit wires in each plane and comparing the event position for each plane, the angle of the muon track can be reconstructed to within 0.5°, on average, in each of two projected planes: up/east and up/north. A 50 mm thick steel plate is situated above the bottom two PWC planes to discriminate between muon tracks which penetrate the steel and electron tracks which stop, shower, or are deflected by the steel. The array collects data at a rate of ~2000 identified muons per second. Added details are available at: http://www.nd.edu/~grand.

3 Data

Data were collected from 21 July 2007 until 8 January 2008 with raw single track muon counts per hut being summed into 10 minute bins. In order to improve data quality and correct for variations in detector sensitivity from both the number of huts active and the quality of those huts, data from only the top four performing huts were used for any given 10 minute period. Using the top four huts eliminates many of the problems with hut quality because most of the failures which occur in the detectors or the hardware cause reductions in count rates such as the presence of hot wires in the detector which are automatically ignored by the detector and all their data disregarded effectively reducing the detector's area.

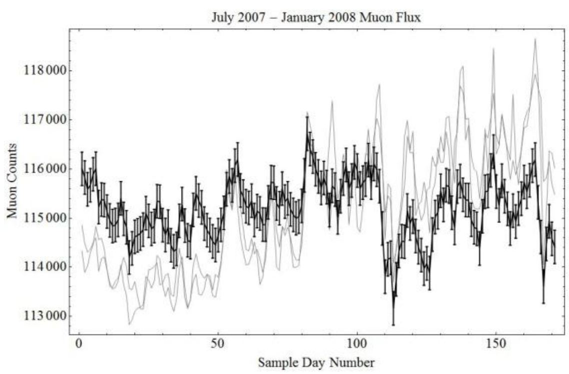

Figure 1. View of the smoothed data from the 171 day time period. The dark line is the temperature and pressure corrected time series while the light lines are the smoothed data before temperature and pressure correction.

In order to eliminate major atmospheric effects the data were corrected for variations in temperature and pressure based upon atmospheric profiles derived from weather balloon flights from five of the surrounding NOAA weather stations and surface pressure measurements from the local NOAA station. Pressure was corrected by using a linear relationship between percentage change in muon flux and percentage change in surface pressure where the constant of proportionality was -0.8. Temperature was corrected by finding the average altitude of pion creation and using a similar linear percentage change relationship where the coefficient was -0.7. The data can be seen in Figure 1. These corrections are important for investigating periodicity since atmospheric pressure also exhibits daily variations due to atmospheric tides [7] which causes suppression of the 2 cycle per day variation since it is out of phase with the effect caused by the IMF (Figure 2).

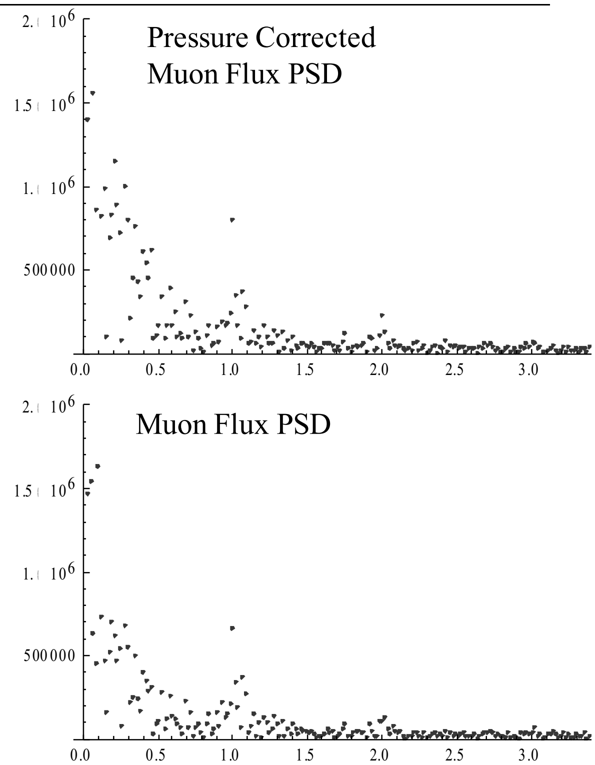

Figure 2. Comparison of the pressure corrected and the raw muon flux. Note the suppression of the 2 cycle/day variation.

4 Observed Periodicity

The periodic variations in the muon can be identified by analyzing the Fourier transform of the corrected muon flux time series. Here in Figure 3 the spectral data for 4 years of muon flux interpolated using nearest neighbor interpolation to insure evenly spaced data points can be seen. In this power spectral density (PSD) there is an obvious 1 cycle per day variation along with higher order harmonics.

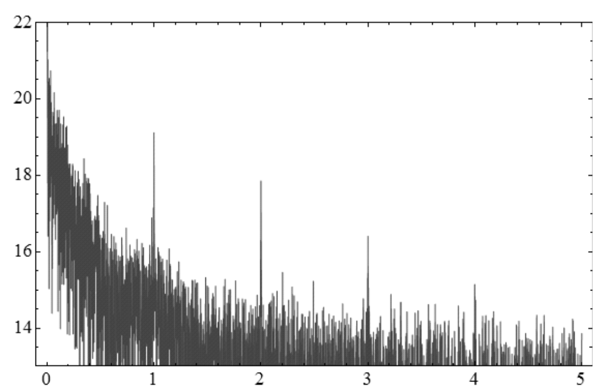

Figure 3. PSD of the 4 years of muon flux plotted on a log scale. Notice the significant peaks at 1, 2, 3, and 4 cycles per day and strong low frequency trends.

The PSD also indicates that there are significant longer term variations to be found in the data however the spectral resolution of the PSD at these frequencies along with the use of interpolation does not permit isolating these features.

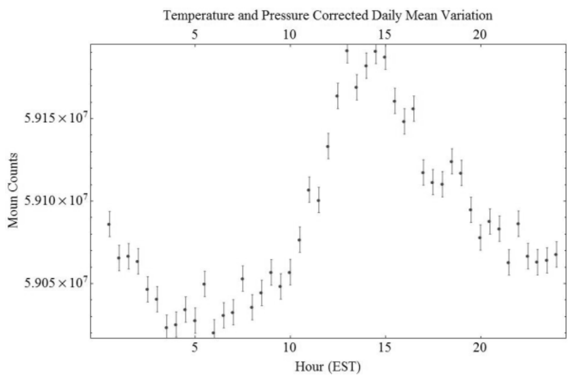

Figure 4. Histogram of muon counts separated into 30-minute bins for the 48 half hour periods in the day.

The finer structure of the DMV can be investigated by using data folding to determine the shape of the DMV where the data is summed into a histogram with 48 bins corresponding to 48 30-minute time periods in the course of a day (Figure 4). This method agrees nicely with previous investigates of the DMV by GRAND [2].

5 Evolution of Daily Variation

The dynamics of the DMV were then investigated by dividing the data set into 113 overlapping 56.9 day periods (8192 samples). Each of these 113 time series were then Fourier transformed so the amplitude and phase of the 1 and 2 cycle per day variation could be found. This analysis reveals significant variations in the phase and relative amplitude of the two components indicating that the standard aggregated view of the DMV is incomplete.

Representative fitted 1 and 2 cycle per day curves can be seen in Figures 9-13 as the DMV evolves over the data set. The dates on these plots reflect the center date of the data series. Figures 5-6 show the evolution of the 1 cycle per day variation which reaches a peak intensity centered around mid October then decreases rapidly around this value and a phase which reaches a maximum in early September and gradually trails off though the end of the year. Figures 7-8 show that the two cycle variation reaches a minimum in early October and subsequently gradually increases, while the phase uniformly increases throughout most of the time series with the exception of the edges. When these variations are combined, very different phenomena can be observed as the DMV is almost entirely 1 cycle in October while at the beginning in August it had a very strong 2 cycle component.

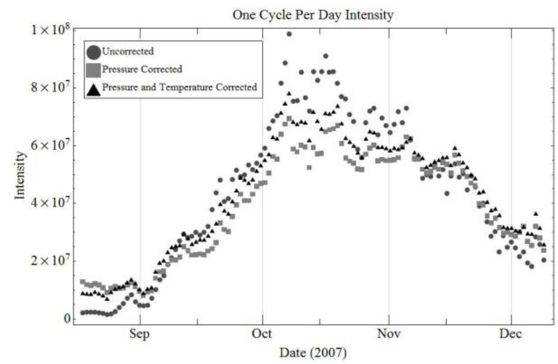

Figure 5. 1 Cycle/Day intensity variation. The different symbols represent different levels of data correction.

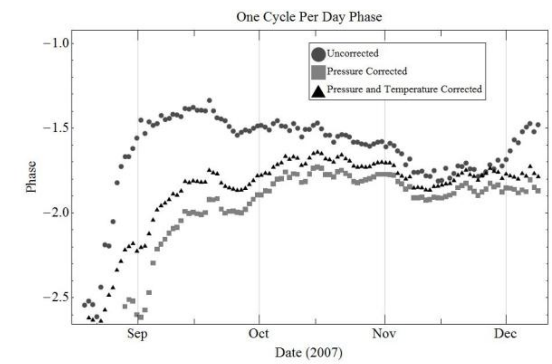

Figure 6. 1 Cycle/Day phase variation

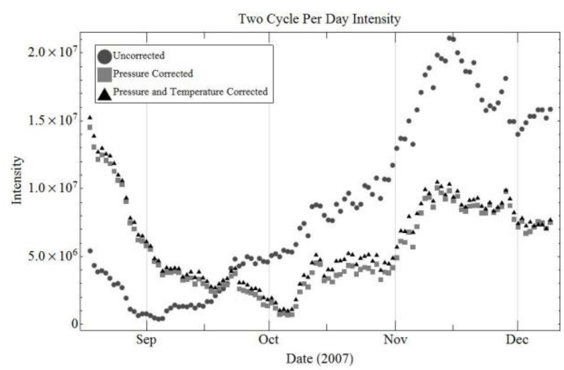

Figure 7. 2 Cycle/Day intensity variation

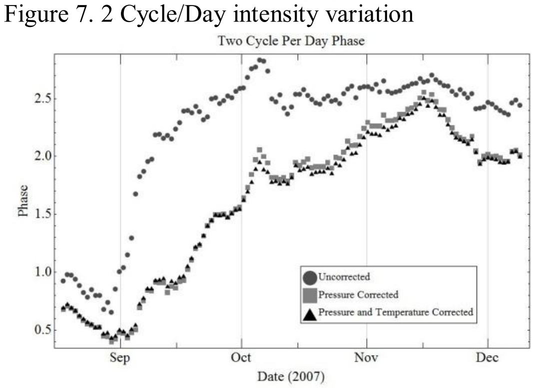

Figure 8. 2 Cycle/Day phase variation

6 Conclusion

In this study, 171 days of data from July 2007 – January 2008 were analyzed to investigate periodic trends in flux on a variety of timescales. Traditional Fourier analysis revealed significant 1 and 2 cycle per day trends which have been well established in the literature and also lower frequency trends which still need to be quantified due to the limited low frequency sensitivity of the analysis. The data were also investigated using less traditional techniques that can reveal interesting phenomena. The time series was divided into smaller pieces so the dynamics of the 1 and 2 cycle variations could be investigated revealing significant changes in both the phase and the intensity of the 1 and 2 cycle trend over time. These variations are probably due to slight changes in the IMF over time but further analysis must be done to relate these two quantities and to better quantify these variations in intensity and phase.

7 Acknowledgements

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8 References

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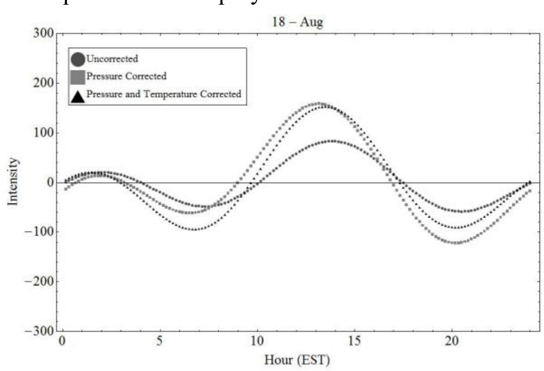

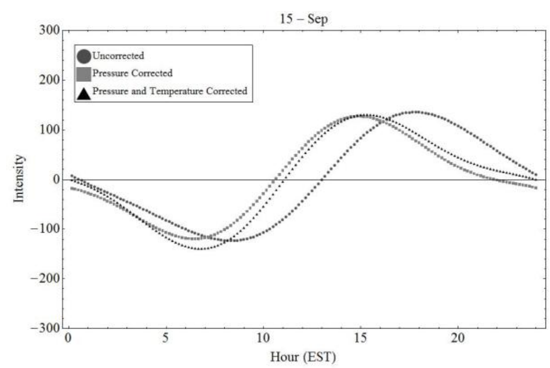

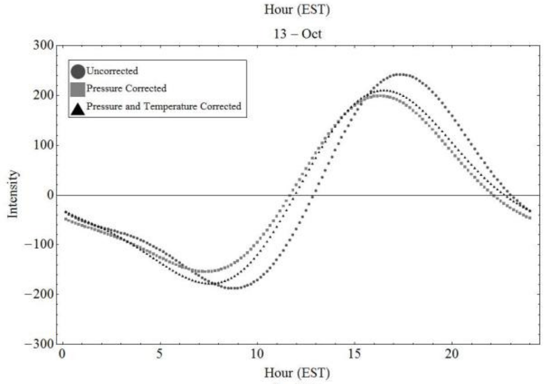

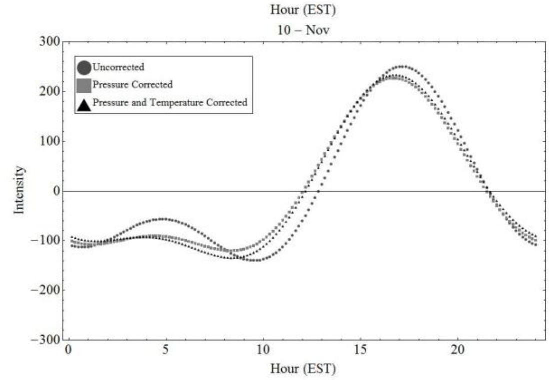

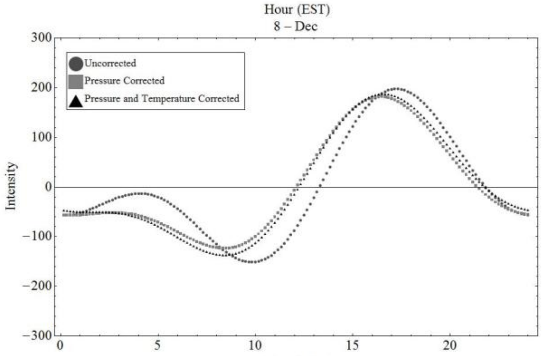

Figures 9-13. Time evolution of the superposition of the 1 and 2 cycle per day variations.