Atmospheric Effects on Muon Flux at Project GRAND

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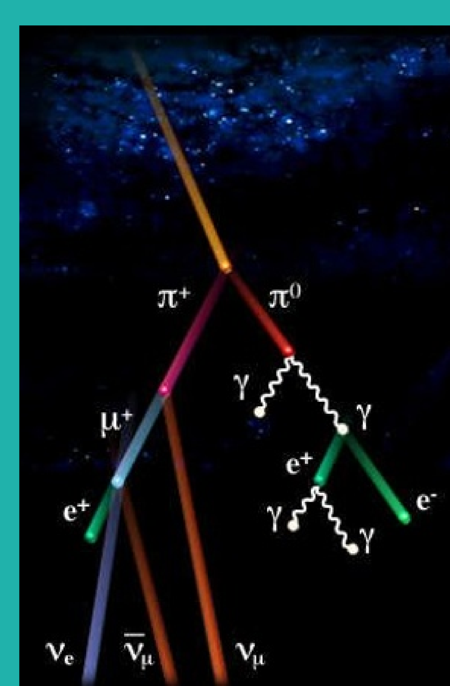
Abstract

GRAND consists of 64 proportional wire chamber detector stations located just north of the University of Notre Dame and has been used to detect muon events since 1995. In this study we have analyzed the data to investigate the contribution of atmospheric pressure and temperature and calculate correction coefficients. This study used GRAND single track muon flux data and NOAA balloon and weather station data from 4 October 2005 through 31 November of 2009 to investigate trends in muon flux caused by atmospheric temperature changes as well as surface pressure variations. To easily consider the effect of temperature, the upper air data sets were reduced to the altitude where the pressure corresponds to the interaction length of a 50 GeV proton, 8.53 kPa. This analysis yields a pressure correction coefficient of -0.98 and a temperature correction coefficient based on creation height of -0.57.

Introduction

Atmospheric conditions have a significant effect on secondary particles making it important to correct for these effects before serious cosmic ray research can be preformed. Atmospheric pressure measured at GRAND is inversely proportional to muon flux since these increases in air mass cause the muons to lose more energy and stop before reaching the surface. Similarly, temperature is inversely correlated with low energy muon flux since as the average temperature of the atmosphere increases the air expands so pions and muons are created higher. This forces muons to travel a longer distance before reaching the detector so they have a higher probability of decaying. To easily study these two effects this project investigated changes in atmospheric pressure and the mean pion creation altitude and the resulting change in muon flux for low energy muon data collected at GRAND between 2005 and 2009.



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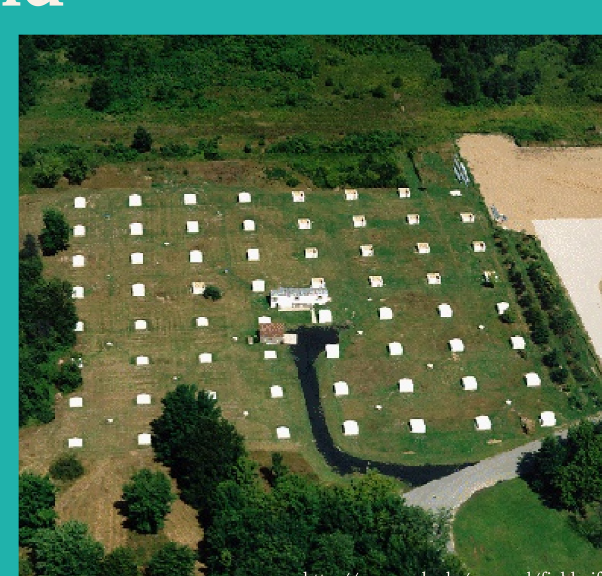
Background

Project GRAND is an array of 64 detector stations located north of the University of Notre Dame at 41.7° N and 86.2° W at an altitude of 220 m above sea level, which tracks both low energy single particle events and high energy showers. The single track muon data used for this experiment is increasingly sensitive to primary energies >10 GeV with a median value of 56 GeV for vertical tracks. Each station contains four proportional wire chamber (PWC) plane pairs which can be used to identify the angle of the muon tracks which can be reconstructed to better than 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:



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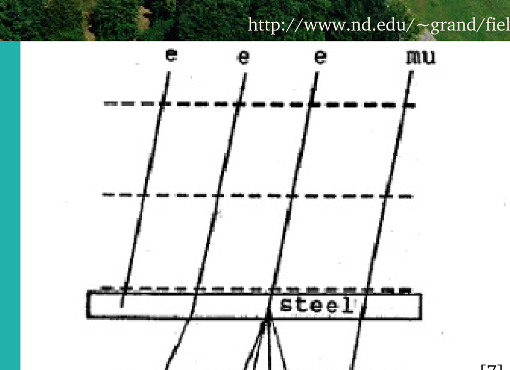

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Pressure

To study the effect of barometric pressure on low energy muons, hourly pressure data[3] was compared to hourly changes in observed muon flux. Because of long term sensor and seasonal variations, only sudden changes in pressure corresponding to fronts passing through the area were used to isolate the effect of pressure on flux. For this analysis a front meant that atmospheric pressure changed by at least 0.068 kPa per hour for at least 9 of 10 consecutive hours. This sudden effect can be approximated via:

$$N = N_0 \exp \frac{\beta(P - P_0)}{P_0}$$

Here N is the corrected rate, N_0 is the measured muon rate, β is the barometric pressure correction coefficient, P is the measured air pressure, and P_0 is a reference pressure. This relationship can be approximated linearly since $\beta(P-P_0)/P_0$ is sufficiently small.

Pressure Results

Nineteen fronts were analyzed using simple regression analysis. A linear fit was then applied to the fractional change in pressure and flux and the slope taken to be the barometric correction factor. These fits reveal a wide range of possible barometric correction coefficients ranging from -0.50 to -1.65 but averaged around -1.00 +/-0.03.

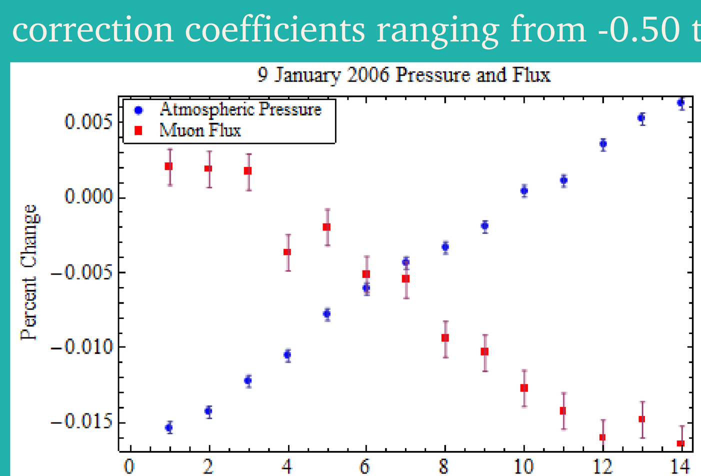


Table of Fronts

Date	Barometric Coefficient	Error	R^2	Pion Creation Altitude (Meters)	Duration (Hours)
1/9/06	-0.945	0.06	0.96	17212	14
1/24/06	-1.205	0.15	0.86	17122	12
1/28/06	-0.802	0.11	0.85	17220	9.6
2/16/06	-0.881	0.04	0.97	17163	16.8
4/3/06	-0.499	0.09	0.79	17233	9.6
12/1/06	-0.885	0.09	0.90	17247	14.4
12/31/06	-0.976	0.06	0.94	17374	16.8
2/19/07	-0.960	0.13	0.80	17017	14.4
12/22/07	-0.99	0.16	0.81	17218	9.6
1/26/08	-1.65	0.10	0.95	17091	12
3/31/08	-1.458	0.32	0.70	17212	9.6
4/8/08	-1.378	0.23	0.69	17248	19.2
5/10/08	-0.698	0.06	0.93	17309	12
1/16/09	-0.992	0.09	0.91	16744	12
2/11/09	-1.057	0.06	0.97	17193	9.6
2/26/09	-0.637	0.07	0.86	17086	14.4
3/10/09	-1.153	0.08	0.93	17276	14.4

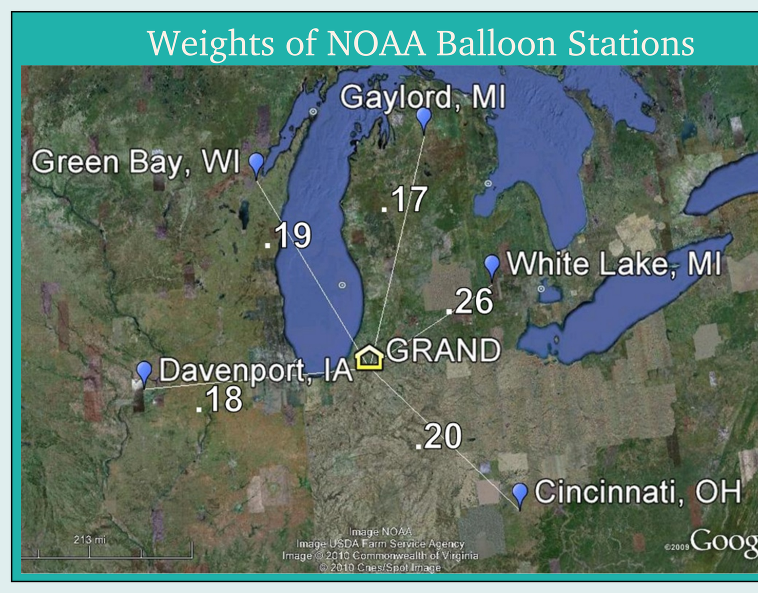
Temperature

Pressure corrected flux and temperature were monitored for four years using twice daily NOAA weather balloon flights[3] to investigate variations due to temperature. The balloon records the air temperature and altitude at various pressures. For each atmospheric profile the mean pion creation altitude for a 50 GeV Proton (8.53 kPa [2]) was interpolated. The pion creation height at GRAND was interpolated using the weighted average of the five nearest weather balloon stations. Since pressure and temperature effects are similar the same correction can be done using:

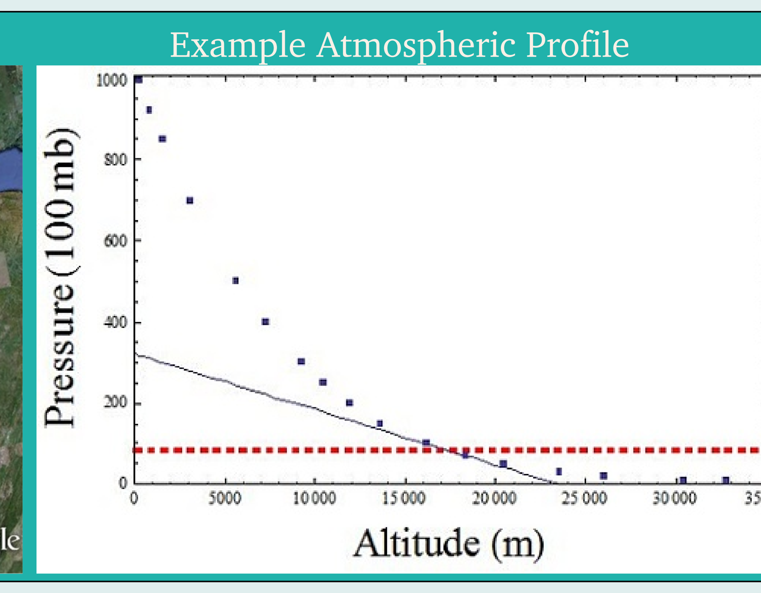
$$N = N_0 \exp \frac{\alpha(H - H_0)}{H_0}$$

Where N is the corrected rate, N_0 is the muon rate, α is the temperature correction coefficient, H is the interpolated height of pion creation, and H_0 is a reference height. Again $\alpha(H-H_0)/H_0$ is small so this equation can be approximated linearly.

Weights of NOAA Balloon Stations

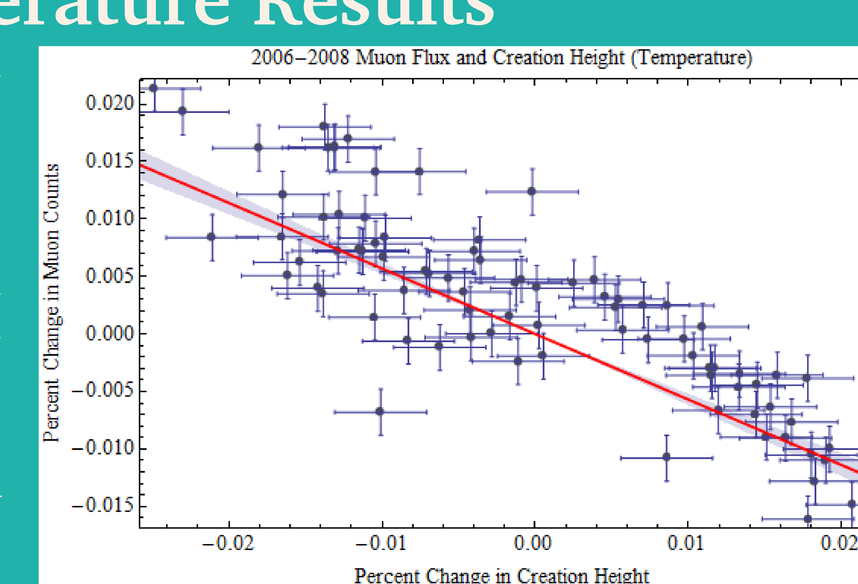


Example Atmospheric Profile



Temperature Results

Muon flux for the first year of data was significantly lower than the other 3 years so it was ignored and only data from 2006-2008 was used. By comparing the interpolated pion creation height and the muon flux data summed over 10 days a correlation coefficient of -0.83 and a correction coefficient of -0.57 +/- 0.04 was found through a linear fit. The 2005 data was also individually analyzed and revealed the same trend.



Conclusion

This analysis has examined the extensive record of GRAND data on disk dating back to 2005 to investigate the relationship between pressure, temperature, and muon flux to establish correction coefficients. The analysis of sudden variations in atmospheric pressure reveals an average correction factor of 1.00 however there was significant variation throughout the experiment probably caused by sensor or seasonal variations. The effect of temperature was investigated by estimating the altitude of pion and muon creation using NOAA weather balloon flights which is correlated with the effective temperature of the atmosphere yielding a coefficient correction of .57, yet there are also non trivial variations. With these pressure and temperature corrections GRAND's muon flux data can now be better used for time series and solar analyses

Acknowledgements

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