Correction Methods for Project GRAND Data

Molly Ball

2011 NSF/REU Program
Physics Department, University of Notre Dame

Advisor: John Poirier

Abstract

Project GRAND is a cosmic ray experiment located north of the University of Notre Dame. It consists of 64 huts of proportional wire chambers that make up a 100 m x 100 m detector array. These detectors identify muons produced when cosmic rays reach the Earth's upper atmosphere. The muon counting rates remain fairly constant, but this is not the case when there are solar flares and coronal mass ejections. An interesting occurrence called a Forbush Decrease was seen in February 2011 in data from the Oulu Neutron Monitor, a lower energy experiment than GRAND. This was caused by a cloud of charged particles and the magnetic fields moving toward Earth which deflect the path of charged cosmic rays that come from outside our solar system and bombard the Earth's upper atmosphere. GRAND's data was examined and a similar decrease at the same time as Oulu was found along with additional phenomenon not seen by Oulu, which usually sees more structure than GRAND due to its ability to detect lower energy particles more easily affected by solar activity. Several steps, such as looking at pressure correction and good hut corrections, have been taken to correct GRAND's data for non-physics effects. An upper air temperature correction remains to be done as well.

1 Introduction

Project GRAND (Gamma Ray Astrophysics at Notre Dame) is a broad air shower array of proportional wire chambers (PWC) that detect secondary muons. Located directly north of the campus of the University of Notre Dame at 41.7°N and 86.2°W at an elevation of 220 m above sea level, the experiment is made up of 64 stations that are arranged in an 8 x 8 grid. Each station contains four PWC pairs with a detection area of 1.29 m^2, giving the experiment a total muon detecting yield of 82 m^2 [1]. Project GRAND runs two experiments simultaneously. One identifies single tracks of individual muons, while the other identifies extensive air showers, which are when multiple stations are hit in a very small period of time [1]. The experiment is most sensitive to primary energies of greater than 10 GeV with a peak sensitivity at 56 GeV for vertical tracks. This makes Project GRAND ideal for studying high energy particles from cosmic rays.

Each of the four pairs of PWC planes contains one plane with 80 signal wires running east-west and the other plane has 80 signal wires running north-south for a total 160 wires in each chamber. The configuration of these two orthogonal planes is used to measure the angle of a charged secondary muon track to +/- 0.5°. All of the pairs of PWC planes, stacked one on top of the other, are separated by 200 mm of space and the bottommost two pairs are separated by a 50 mm thick steel plate that helps to differentiate between muons and electrons. When charged particles move through the detectors, several interactions can occur. If the charged particle is a muon, it will travel in a straight line directly through all of the PWC pairs. If the charged particle is an electron, it will either be completely stopped, start a shower, or scatters when it hits the steel plate. The plate is 96% accurate in distinguishing between muon and electron, but in view of the fact that the number of electrons seen at ground level is only a third of the number of muons that accuracy is closer to 99%.

The PWC chambers are filled with a gaseous mixture of 80% argon and 20% carbon dioxide. When a charged particle like a muon or an electron passes through a chamber, it will ionize the gas and a trail of ions will be left. These ionized particles will move through the chamber and as they do so will collide with other gas molecules. A current is formed on the closest signal wire that is amplified to denote the position of the wire in the chamber therefore the position of the particle.

Identifying the x-value of each wire hit will result in finding the angle of the muon track geometrically.

2 Cosmic Ray Effects

Project GRAND was established to do cosmic ray astrophysics, which investigates particles (or rays) that arrive at the earth's surface from the sun and other galaxies. When cosmic rays hit earth's atmosphere, they collide with air nuclei, typically oxygen or nitrogen, and create secondary particles, such as pions. These pions quickly decay into muons that are able to reach earth's surface to be identified by muon detectors. Project GRAND has the ability to detect rises in ground level muon flux that are associated with powerful solar flares as well as a Forbush decrease which is a rapid decrease in cosmic ray intensity followed by a slower recovery back to the normal muon flux. Forbush decreases are often caused by coronal mass ejections (CME), a massive burst of solar wind, light isotope plasma, and magnetic fields rising above the sun's corona and being released into space. This ejected material consists of charged particles with magnetic fields. Traveling at an average of 500 km/s, CMEs will reach the earth in a matter of days and if the CME is strong, detectors will be able to see the Forbush decrease. The magnetic fields will disrupt the particles heading toward earth and deflect some of the cosmic rays from reaching the atmosphere causing a decrease in cosmic ray detection. Over just a few hours this decrease transpires, but it takes several days for the solar cosmic ray intensity to return to normal.

3 Analyzing Forbush Decrease of February 2011

There were several incidents of activity on the surface of the sun in the month of February, which may be an indication that the sun is coming out of a solar minimum in its normal eleven year solar cycle. The strongest of this activity was a X2 flare on February 15, 2011 with a peak at 1:56 UT [2]. Moving with a speed of about 900 km/s, the CME created by this flare was expected to reach earth's atmosphere early on February 18, 2011. Several different detectors were examined to see if they saw any special phenomenon during this time period. The main detector that was inspected was the Oulu neutron monitor, which identifies secondary particles at a lower primary energy than Project GRAND. This means Oulu would have a better chance of seeing structure due to a Forbush decrease. The plotted data for February 12, 2011 00:00 UT to February 28, 2011 07:00 UT from Oulu can be seen in Figure 1. This neutron monitor saw definite structure in their neutron count with a 4% drop in a couple of hours and a gradual rise back to the normal count which is characteristic of Forbush decreases [3].

After seeing the structure in Oulu's data, Project GRAND's data was examined. The structure seen on GRAND's website seemed to be more dramatic than Oulu. The data for GRAND can be seen in figure 2. GRAND's data needed to be analyzed in more detail to make sure all non-physics effects have been properly taken into account.

4 Correction Methods

When the cosmic rays come into earth's atmosphere, several factors can have an effect on them. The atmospheric pressure is one of the most influential factors on particles moving toward the surface of the earth. When the pressure is high, it takes particles more energy to reach the earth's surface, meaning fewer muons reach the detectors. The opposite effect is true for lower pressure periods. A pressure correction that is completely accurate is essential if the physics of cosmic rays is to be studied. Without a proper pressure correction, the effects of the earth's atmospheric conditions would overshadow the physics. The first check was to verify whether the GRAND's data lab website was doing the pressure correction properly. Several time periods were checked and the conclusion was that the website did not perform the pressure correction accurately. A new program had to be written to correctly handle the pressure correction and pressure corrections can now be made quite easily.

After applying the pressure correction, the data from the February period still showed more structure than that of Oulu so further investigation was necessary. Additional corrections adjust for disabled stations or stations having problems with their counts. There is no simple way to check to see if the program that does this correction is working correctly, so another program was needed to verify this. This new program was written to take dayfiles from Project GRAND and find the stations with the highest counts for each ten-minute period that the experiment records, it would then combine the top four muon counts into a single count. This is not how the normal correction, known as the “good hut correction” works from GRAND’s data lab website. When a hut has a problem the efficiency goes down, meaning the muon count will decrease. By applying this top four station correction, it is possible to circumvent any problem that might be associated with the good hut correction. A pressure correction could then be applied to the count found by the top four station correction and data that was both pressure corrected and provisional correction for top stations would be available. After completing this step for GRAND’s February data, it was found that it was still resembled the original count data that seemed to have too much structure.

5 Other Possible Problems

Although several steps were taken that would lead to a more accurate muon count, there is a great deal of structure still present in Project GRAND’s data and this leads to the notion that there might be more corrections or repairs that need to be done. December 2010 through March 2011 was examined and there was found to be a definite correlation between average daily temperature and muon count. A section of this comparison can be seen in figure 3. At the end of December, there is a sharp increase in the temperature, which corresponds to a decrease in the counting rate. This indicates that a proper temperature correction needs to be performed. This will be something that Project GRAND students will work on in the future. Another potential cause for the structure in GRAND’s data is gas leakage to the stations. This could affect the muon count rate if the gas flow wasn’t at a level it should be and the detector efficiency would be decreased. These are both potential problems that will be examined in order to verify that Project GRAND’s data is accurate.

6 Conclusion

When looking at the activity seen by detectors during the solar active period in the middle of February 2011, specifically a suspected Forbush decrease on February 18, 2011, it was noted that data from Oulu Neutron Monitor in Finland and Project GRAND didn't correspond with each other. The interesting observation that accompanied this was that Project GRAND, a higher energy experiment, saw a significant amount structure that was undetected by Oulu, which typically is able to see more activity due to its lower energy observations. Several methods of correcting the raw data were implemented to try and decipher if the data reported by GRAND's data lab website was accurate and there is still an ongoing effort to establish this. It is necessary to exhaust every possible explanation for the structure seen by GRAND before the data can be viewed as significant cosmic ray activity.

Acknowledgements

I would like to thank my advisor, Dr. John Poirier, for being very helpful and patient as I conducted by research. He made my REU experience very enjoyable as well as enlightening. I would also like to acknowledge the work of Calvin Swartzendruber, Chris Windbigler, and Evan Grimes with helping to maintain the detectors. I would like to thank Chris D'Andrea for his assistance when we struggled to find the next steps to take. Finally, I would like to thank Dr. Garg and the entire Notre Dame Physics Department for making this summer an exciting and educational experience.

References

[1] J. Poirier, C. D'Andrea et al (2007), Status report on project GRAND, *30th International Cosmic Ray Conference (ICRC).*

[2] NASA, http://www.nasa.gov/

[3] Oulu Neutron Monitor, http://cosmicrays.oulu.fi/

[4] NOAA National Weather Service, http://www.crh.noaa.gov/

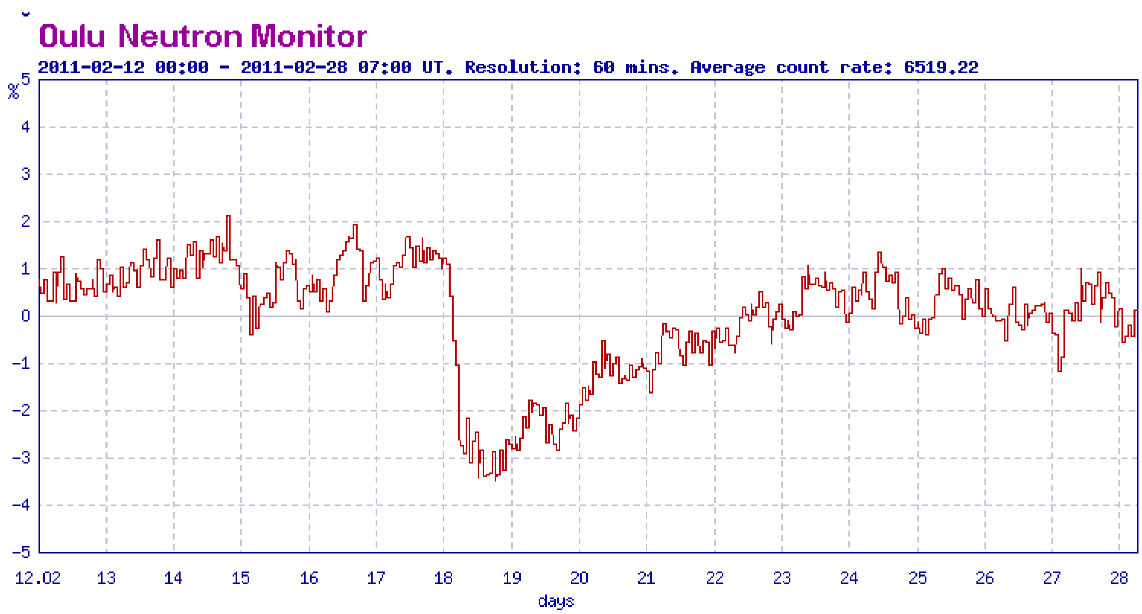

Figure 1: This is the graphical representation of Oulu Neutron Monitor's data. It shows a rapid decrease of about 4% in neutron count at the beginning of February 18 followed by a gradual increase back to normal [3].

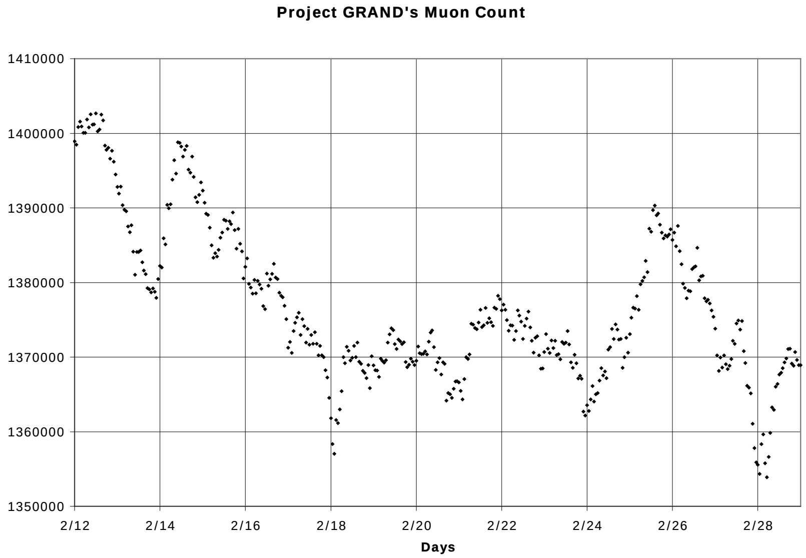

Figure 2: This is Project GRAND's count data after top stations have been selected and after corrections for pressure have been made. It sees a slight drop in count around the beginning of February 18, but it doesn't seem to be as significant as Oulu's data.

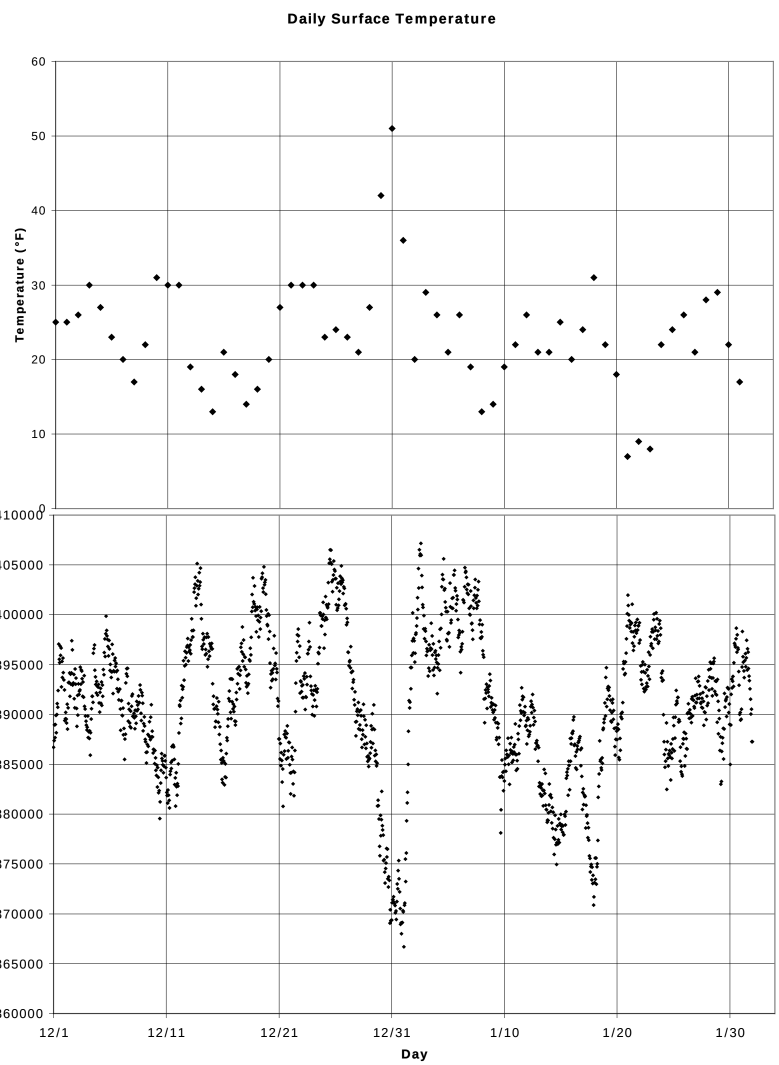

Figure 3: These two graphs show the correlation between surface temperature (top) and GRAND's muon count (bottom) [4].