Cosmic ray detection and magnetic cloud volatility analysis suitable for high school student research

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Abstract

The QuarkNet is an association of Femi National Lab physicists, college physics professors and high school physics teachers with multiple missions which include enhancing science and engineering knowledge through hands-on experience among high school students. Besides building cosmic ray detectors, we instituted a related activity in the studying of cosmic ray and/or solar proton induced muon production. This activity concerns whether the muon flux fluctuation has a relationship to solar eruption event effects. Mathematical skills at the pre-calculus level in the high school curriculum was found to be sufficient to perform the necessary analyses. The analysis of a magnetic cloud event detected by the ACE spacecraft on April 14-15, 2013 was presented as an example. Together with the fast time resolution with sub-minute data binning capability of the QuarkNet detector, future muon fluctuation volatility analysis by high school teachers and students for solar event analysis projects is discussed.

Keywords

Muon detection, fluctuation volatility, solar eruption, magnetic cloud, high school research project

Introduction

QuarkNet is an association of physicists, college physics professors and high school physics teachers dedicated to infusing the standard curriculum with contemporary physics. It provides summer programs for teachers and activities for students [1]. Each center is based at a college with some connection to high energy physics. Surprisingly, New York City has not had an active QuarkNet center for a long time. In 2016, Queensborough Community College became such a center. Prof. Raul Armendariz, the center's lead, teaches a course in student scientific research at QCC. He has focused the course's activities on the creation of a new array of cosmic ray detectors. The proposed CUNY array will consist of some 20 to 40 cosmic ray detectors at City University of New York campuses and other college campuses around the city, supplemented by some at local high schools. Each detector will consist of 2 to 4 scintillator plates mated to photomultiplier tubes. Cosmic rays entering the atmosphere cause showers of muons (and other, less penetrating, particles beyond our detector's ken). A muon passing through a scintillator plate leaves behind a little energy in interacting with the plate's doped plastic material. The scintillator plate absorbs this energy and emits light of a known frequency. The plate is wrapped in reflective material, so the light bounces around until it finds the photomultiplier tube, which absorbs it and emits a signal, processed by a nearby computer. Data from each computer in the array will be automatically analyzed at QCC. The arrays pursue serious scientific research, and high school students participate actively in this research. Student research begins with learning practical hands-on laboratory skills in assembling the detector components. Fermilab has donated the scintillator plates, pieces of old scintillator panels no longer in use. Fermilab roughly sliced the scintillator panels into 3 pieces to facilitate storage. Students begin by sanding and polishing each rough plate edge into transparency.

In addition to building cosmic ray detection detectors, our department instituted an activity associated with the study of cosmic ray and solar proton-induced muon production: to determine whether there exists a relationship between a magnetic cloud's muon flux and simultaneous events due to solar eruptions. Using mathematical skill at the pre-calculus level in the high school curriculum, we have built a protocol for the muon study via the volatility concept. The basic spreadsheet tools such as copy-paste and histogram utilities are sufficient for data analysis. Given a random series, volatility measures the fluctuation after the trend is subtracted and is simply related to the increment change in a small time interval. Most high school students are expected to communicate with their parents about participation in the cosmic ray study project. A practical explanation of volatility in relationship to the stock market to the concerned parents would be helpful. There is a volatility index example that hedge/pension fund manager can trade. Volatility is a concept made popular by the physicist Black and the Black-Scholes model gave foundation in starting the option trading in Chicago around 1973. The 1997 Nobel Prize Economics was related to the volatility mathematical foundation [2].

A magnetic cloud event detected by ACE spacecraft on 2013 April 14-15 has been analyzed and the results have been published on open access platform accessible by high school teachers and students [3].

The Muon Flux Data

The 2013 April 14-15 Magnetic Cloud has been analyzed and reported [3]. The graph on Figure 2 of Reference-3 boxed the magnetic event from April 14 at 15:56 to April 15 at 17:56. We have downloaded pressure-corrected muon 1-min flux data in the same time window from Athens Center, http://www.nmdb.eu/nest/, and imported onto Microsoft Excel spreadsheet for further analysis.

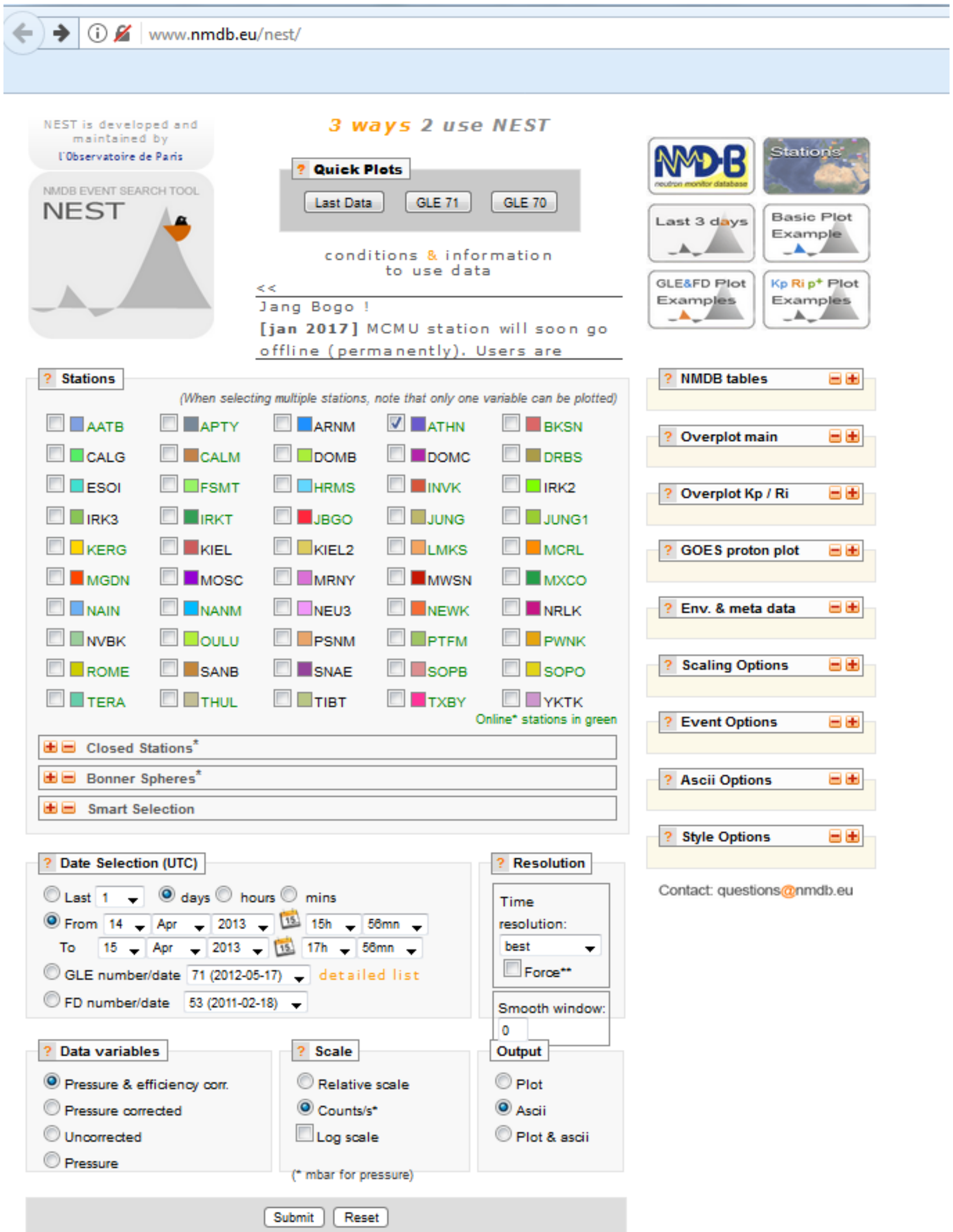

Figure 1: The muon data download web page

The Volatility Analysis & Results

Given Excel Cell-A1 and Cell-A2 contains muon data at two different times, the analysis started with the calculation of (A2-A1)/A1, the increment change. The histogram of the increment change data would carry the volatility as its width if it is a Gaussian distribution.

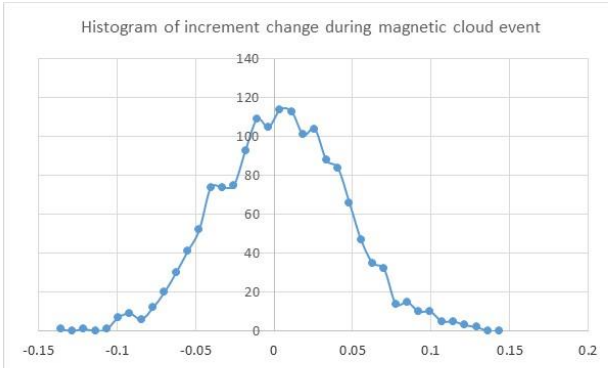

Figure 2: The histogram of muon data increment change during the magnetic cloud event of April 14-15, 2013, with time window specified on Reference 3.

The increment change histogram for the previous 24 hours before the magnetic cloud event showed a smaller width as displayed in Figure 3.

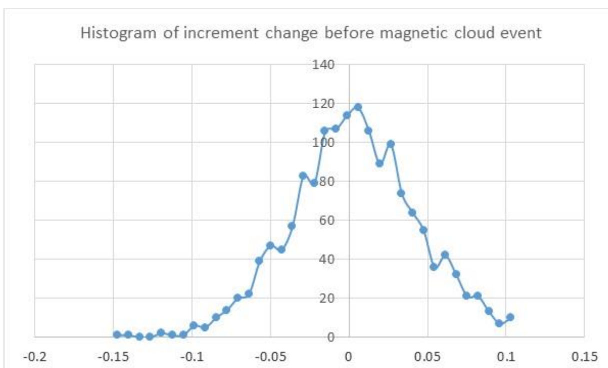

Figure 3: The histogram of muon data increment change 24-hour before the muon data of Figure 2.

The increment change histogram for the next 24 hours after the magnetic cloud event showed a width retention as displayed in Figure 4. This retention, about 90% of the width seen during the magnetic cloud event in Figure 2, is probably due to a solar proton peak event as detected by the GOES-13 spacecraft on the following day.

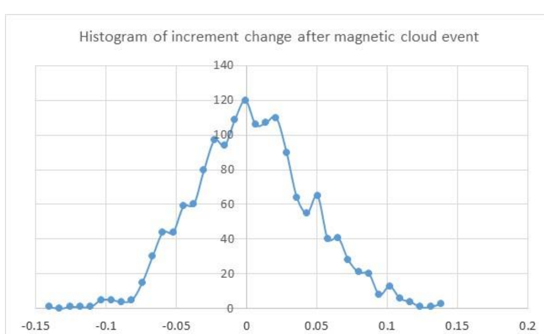

Figure 4: The histogram of muon data increment change 24-hour after the muon data of Figure 2

The GOES-13 data showed a peak on the following day after the magnetic cloud event, as displayed in Figure 5.

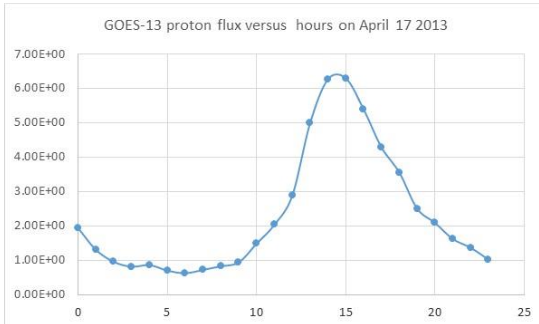

Figure 5: The GOES-13 Channel-1 (0.78-4.2 MeV) proton data versus hours on April 17 2013, the day after the magnetic cloud event.

Together with the fast time resolution with sub-minute data binning capability of the QuarkNet detector, future muon fluctuation volatility analysis by high school teachers and students for solar event analysis projects can be conducted simultaneously with the hands-on experience gained in the building of the QuarkNet detectors. The "Learning with Intent" will be fully integrated into the QuarkNet mission of high school outreach.

Discussion

Besides volatility study using 1-min flux data, other studies such as cosmic ray muon flux yearly variations correlation to clouds, stratospheric sudden warming (SSW) events correlation to cosmic ray muon flux daily variations, etc. are also available as high impact projects for students [4, 5]. The topics of borehole-sized muon detector for oil drilling application, muon spin interaction with brain ferritin for Alzheimer's disease research, local muon density spectra for ultrahigh energy cosmic ray research, ground level high flux muon puzzle research, etc. are also suitable for knowledge broadening and would encourage high school graduates to select engineering in college [6, 7, 8, 9].

Conclusions

The volatility protocol for the studying of muon flux fluctuation suitable for high school research was conducted using Athens Center muon flux data. It is expected that the fast detector developed by QuarkNet would enable sub-minute data binning for an in-depth volatility study on a smaller time scale in the near future, including the events triggered by cosmic rays outside Milky Way [10].

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