Neutron Monitor Forecasting of Radiation Storm Intensity

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***Abstract*. We seek to determine whether South Pole neutron monitor observations can be used to predict radiation storm intensity as measured from GOES spacecraft. Using the "Polar Bare" method which compares a standard neutron monitor (NM64) and a monitor lacking the usual lead shielding (Bare), we estimate the particle spectrum from the Bare and NM64 count rates. Selected ground level enhancements (GLEs) are divided into two groups. One group consists of 12 GLEs where spectra derived from the South Pole observations are compared to 4 proton energy channels (P4-P7) from GOES. The other group consists of 7 GLES where spectra are additionally compared to higher energy proton channels (P8-P11). The second group of 7 GLEs is a subset of the first group of 12 GLEs. We conclude that South Pole GLE observations can be used to predict radiation intensity of the higher energy proton channels from GOES.**

***Keywords*: Ground Level Enhancement, Solar Proton Event, Neutron Monitor**

I. Introduction

Relativistic solar particles provide an important observational basis for understanding acceleration processes near the Sun. When a high enough flux of solar nucleons with energy greater than a few hundred MeV strikes Earth's atmosphere, the nuclear byproducts cascade to Earth's surface resulting in a "ground level enhancement" (GLE). Beginning with the first recorded event on February 28, 1942, a total of 70 events have been identified through December 13, 2006. When planning for radiation hazard mitigation in future human missions into deep space it is important to recognize the extremely large fluctuations in magnitude that solar particle events display.

Some previous studies determined GLE spectra from measurements at a single location, by exploiting the difference in energy response between a standard neutron monitor (NM64) and a nearby monitor that lacks the usual lead shielding ("Bare"). The method is similar in concept to the technique of using nearby stations at differing altitudes to obtain spectral information [1]. The Bare/NM64 method was applied to five 1989 GLEs (events 41-45) by Bieber & Evenson [2]. More recently, they applied the method to GLE59 on July 14, 2000 [3] and to GLE69 on January 20, 2005 [4]. The present study aims to determine whether measurements made during the GLE peak have predictive power for particles of lower energy. Particles in the tens to hundreds of MeV energy range arrive later than the GLE particles because they are slower, but they pose the more serious radiation hazard for astronauts.

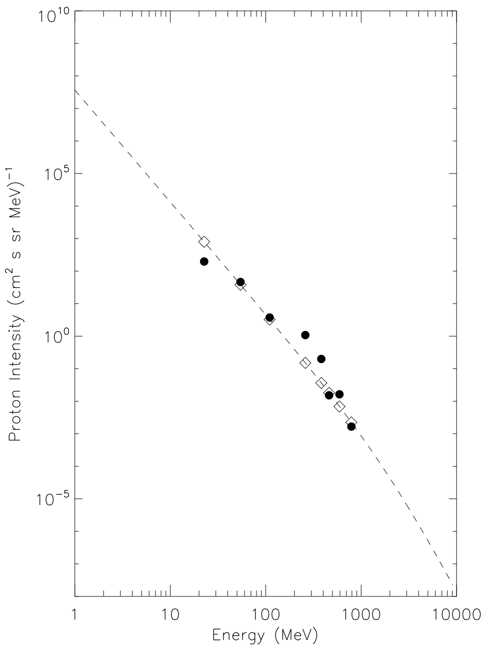

Fig. 1: Energy spectrum of the SPE of July 14, 2000 (Bastille event). The dashed line is the spectrum derived from neutron monitor observations at the *time of the neutron monitor peak*. Filled circles are 8 GOES channels plotted at the mean energy of the channel at the *time of the peak for the corresponding GOES channel*. Open diamonds are the predicted proton intensity of the GOES channels, derived by extrapolating the neutron monitor spectrum downward in energy.

II. Data and Method

For many years there were two types of neutron monitor at South Pole, a standard 3NM64 and a set of "bare" (without the lead producer) BP-28 detectors. These "Polar Bares" have a lower counting rate and are much more sensitive to the environment than the standard monitor but, particularly since they are at mountain altitude, they have an unusually low threshold.

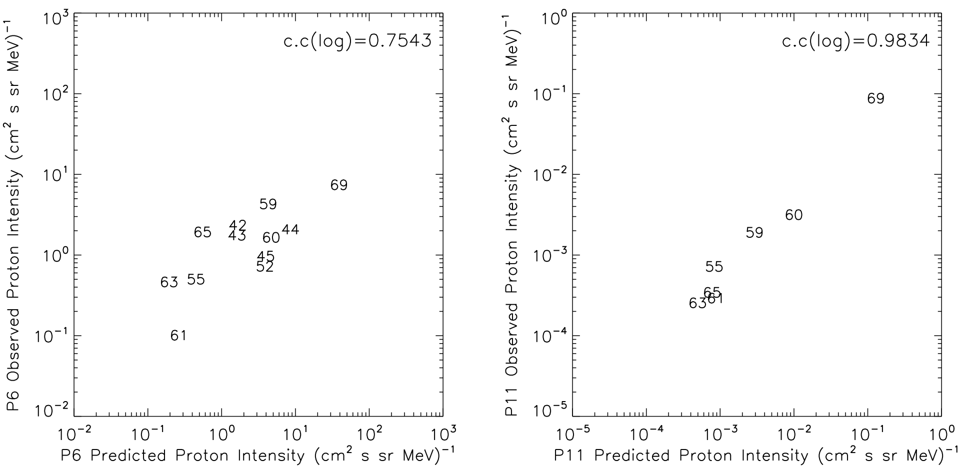

Fig. 2: Comparison of peak intensities observed by GOES and predicted from spectra obtained at the (earlier) GLE peak for the P6 and P11 proton energy channels

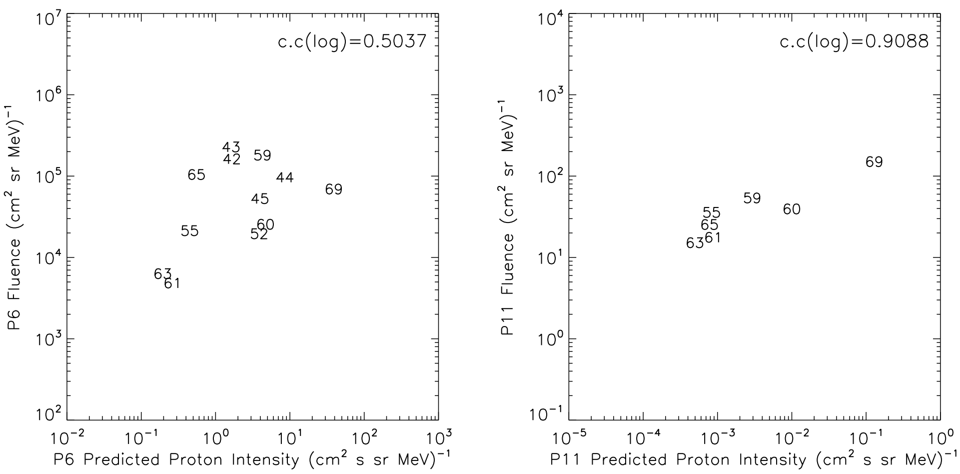

Fig. 3: Comparison of observed GOES fluence with predicted intensity from GLE observations for proton channels P6 and P11

We have used 2-minute or 5-minute averaged data from these detectors to determine energy spectra for 12 GLEs.

In order to compare to the spectrum of solar particles at lower energy, we used GOES 5-minute averaged proton channel intensity from P4 to P11. In detail, data of GOES7 are used for GLE42-GLE52, data of GOES8 for GLE55, data of GOES10 for GLE59-GLE65, and data of GOES11 for GLE69. The 12 GLEs are divided into two groups based on the range of energies available from GOES. The first group comprises all 12 GLEs from GLE42 to GLE69 using channels P4-P7. The second group is the subset of 7 GLEs from GLE55 to GLE69 when the 4 higher energy proton channels (P8-P11) are available.

The spectrum of relativistic solar protons can be estimated from the count rates of the South Pole standard NM64 neutron monitor and the nearby Polar Bares [2]. The Polar Bare is relatively more sensitive to low-energy primaries, and it records a higher percentage increase than the standard NM64 owing to the soft spectrum of solar cosmic rays. Count rates are expressed as a percent increase over the pre-event galactic background. All data are 2-minute or 5-minute averages corrected to standard pressure (760mmHg) using an assumed solar particle absorption length of 100 gcm^{-2}. With the aid of yield functions provided by Stoker [5], the ratio Bare/NM64 can be translated into a spectral index. Further, with spectral shape known, the actual count rate can be used to determine the absolute spectrum amplitude.

Two sets of constants for the Dorman function were suggested by Stoker [5]. We chose to use alpha=7.846 and k=0.940. We also assume a spectrum in the form of a power-law in rigidity ($P^{-\gamma}$, with P the rigidity and γ the spectral index) to an upper cutoff at 20 GV. Figure 1 shows an example of this analysis, compared with GOES data from the same event. The spectral index approaches a value $\gamma \sim 5$, which is quite typical for GLEs [6].

III. RESULTS

Figure 2 compares peak intensities as observed by GOES and predicted from South Pole GLE spectra for the P6 and P11 proton energy channels (In the case

TABLE I: Linear and Logarithmic Correlation Coefficients. Left: Correlation coefficients between observed and predicted peak intensity of proton channels. Right: Correlation coefficients between observed fluence of proton energy channel and predicted intensity of proton energy channel.

Proton	Energy Range	Peak Intensity		Fluence	
Channel	(MeV)	Linear	Logarithmic	Linear	Logarithmic
P4	15-40	0.0132	0.4091	-0.0504	0.4093
P5	40-80	0.2336	0.5113	-0.1058	0.3763
P6	80-165	0.8631	0.7543	-0.0203	0.5037
P7	165-500	0.9376	0.8687	0.0386	0.5888
P8	350-420	0.9919	0.9758	0.6903	0.8196
P9	420-510	0.9991	0.9661	0.7090	0.8335
P10	510-700	0.9996	0.9823	0.8346	0.8665
P11	> 700	0.9992	0.9834	0.9657	0.9088

of GOES events with multiple peaks, we used the first peak.). The intensity of each proton energy channel is predicted by spectra obtained at the GLE peak using the Polar Bare method [2, 5]. As the energy of the proton channel gets higher, the correlation of observed and predicted intensities gets progressively better.

Figure 3 is similar to Figure 2, except the comparison is with the fluence from GOES. The fluence of each proton channel is time-integrated flux from onset to end of the event, determined as the time to get back the pre-event intensity level. Correlation between fluence and predicted intensity also improves with increasing energy of the proton channel.

Correlation coefficients of the data in Figures 2 and 3 are given in Table 1, calculated both for linear and logarithmic representations of the data. This table confirms, and quantifies, the visual impression that the predictive power of the spectra determined from the South Pole increases progressively with increasing GOES energy channel.

We note that the peak of the GLE precedes the peak of proton energy channel in most events. For instance, for the event displayed in Figure 1 (Bastille event), the neutron monitor peak preceded the P4, P6, and P8 peaks by 320, 305, and 30 minutes respectively. As the energy of proton channel gets higher, the time interval between two the peaks gets shorter. Typically the interval is less than 60 minutes for proton channels higher than P8.

IV. SUMMARY

The peak spectra of the selected 12 GLEs recorded by South Pole neutron monitors were used to predict peak intensity and fluence for proton energy channels P4-P11 from GOES. From this comparison we summarize as follows:

1) As might be expected, correlation coefficients between observed and predicted peak intensity of GOES proton energy channels are highest in the higher energy proton channels.
2) Correlation coefficients between fluence of proton energy channel and predicted proton energy channel intensity are also highest in the higher energy proton channels.
3) As the energy of the proton channel gets higher, the time interval between peaks of GLE and proton energy channel gets shorter.
4) South Pole GLE observations can be used to predict radiation intensity, and fluence of the higher energy proton channels from GOES.
5) There may be a limited predictive capability for energies as low as 15 MeV (logarithmic correlation coefficient $\sim$ 0.4), though this result has marginal significance ($\sim$ 90%) with the present limited data set.

V. ACKNOWLEDGEMENTS

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