Largest GLE in Half a Century: Neutron Monitor Observations of the January 20, 2005 Event

John W. Bieber[a], John Clem[a], Paul Evenson[a], Roger Pyle[a], Marc Duldig[b],
John Humble[c], David Ruffolo[d], Manit Rujiwarodom[e] and Alejandro Sáiz[d,e]
(a) Bartol Research Institute, University of Delaware, Newark, DE 19716, U.S.A.
(b) Australian Antarctic Division, Kingston, Tasmania, Australia.
(c) School of Mathematics and Physics, University of Tasmania, Hobart, Tasmania, Australia.
(d) Department of Physics, Faculty of Science, Mahidol University, Bangkok, Thailand.
(e) Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand.
Presenter: John W. Bieber (john@bartol.udel.edu), usa-bieber-J-abs1-sh15-oral

Within a 6-minute span on January 20, 2005, the count rate registered by a neutron monitor at the sea level station of McMurdo, Antarctica increased by a factor of 30, while the rate at the high-altitude (2820 m) site of South Pole increased by a factor of 56. The size of the increase at McMurdo qualifies it as the largest observed at sea level since the famous 1956 event, while the increase at South Pole may have been the largest (in percentage terms) ever registered by a neutron monitor. This paper uses data from the "Spaceship Earth" network of neutron monitors to characterize the time evolution of cosmic rays during the event. We also investigate spectral evolution using multiplicity data from a specially instrumented mobile monitor that was located in McMurdo Sound at the time of the event.

1. Introduction

The Sun occasionally emits cosmic rays of sufficient energy and intensity to increase radiation levels on the surface of Earth. From the time systematic observations by neutron monitors began in the 1950's, such "ground level enhancements" (GLEs) have occurred at a rate of about 15 per solar cycle. The largest GLE on record is the famous 1956 event [1] during which radiation levels near sea level increased by as much as 47 times in some regions. Several additional giant GLEs were recorded in the pre-neutron monitor era by ionization chambers [2,3], but until this year no events in the giant GLE class (characterized by an increase of, say, 5 times or more in the sea level neutron rate at some location) had been observed since 1956. It is important to recognize the extremely large fluctuations in magnitude that solar particle events display when planning for radiation hazard mitigation in future human missions into deep space.

2. The Return of Giant GLEs

Over a 6-minute span on January 20, 2005, the neutron rate at the sea level station of McMurdo, Antarctica increased by a factor of 30, while the rate at the high-altitude (2820 m) station of South Pole increased by a factor of 56. As shown in Figure 1, other stations observed an increase by only a factor of 3 or so. While large by recent historical standards, this does not approach the huge increase seen at McMurdo and Pole. Apparently this event was extremely anisotropic.

The size of the increase at McMurdo qualifies as the largest sea level increase since 1956; hence the January 20 event was the second largest GLE ever recorded. For comparison Table 1 lists the factor increase measured at some of the stations that were taking data during the 1956 event. The increase measured at South Pole may be the largest ever recorded by a neutron monitor. However, this distinction is largely due to South Pole's unique location that is both high latitude and high altitude. Corrected to sea level, the South Pole increase over the Galactic background would have been "only" a factor of ~23.6.
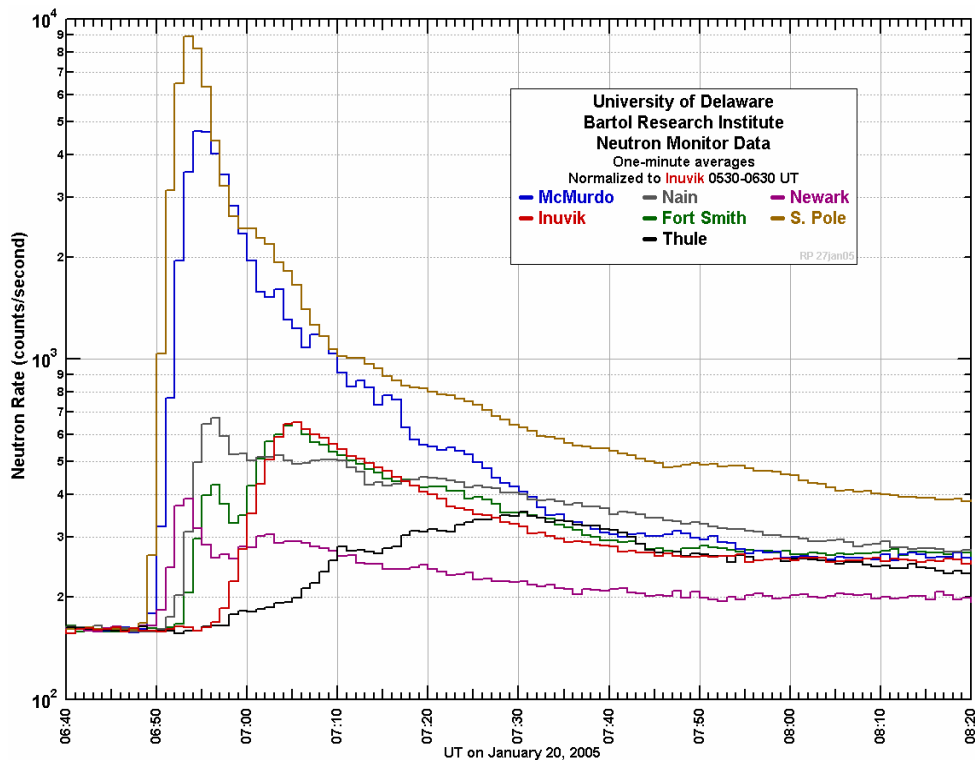
Figure 1. On January 20, 2005 the Sun emitted cosmic rays of sufficient energy and intensity to increase radiation levels on Earth's surface. The GLE was especially intense at South Pole (highest peak) and McMurdo, Antarctica (second highest), where radiation levels increased by factors of 56 and 30, respectively, in a span of 5 minutes. The McMurdo increase was the largest observed at sea level since 1956.

3. Energy Spectrum

3.1 Polar Bare Method

In addition to the standard NM64 neutron monitor, our observing station at South Pole includes a set of counters that lack the usual lead shielding. These "polar bare" detectors have a lower energy response than the NM64, which enables us to derive spectral information by comparing the relative response of the two types of detector to a solar particle event.

As shown in Figure 2a, the polar bares exhibit a larger increase relative to the pre-event Galactic background than do the NM64 detectors. This indicates that the spectrum of the January 20, 2005 GLE is softer than the Galactic spectrum, as is typical of GLEs.

Table 1. Comparison of the Giant GLEs of 1956 and 2005

Station	Total Count Rate At Peak Relative to Pre-Event Galactic Background	Time Averaging Interval (min)
February 23, 1956 GLE		
Leeds	46.8 X	15
Climax	29.1 X	15
Chicago	20.8 X	15
Albuquerque	13.4 X	10
January 20, 2005 GLE		
South Pole	56.0 X	1
McMurdo	30.0 X	1
Nain	4.1 X	1
Thule	2.2 X	1

Figure 2b displays the ratio of the polar bare increase to the NM64 increase (both expressed relative to their respective pre-event Galactic backgrounds). A clear dispersive onset is evident, as the fast particles arrive earlier than the slower ones, resulting in an initial hard spectrum which rapidly softens. The monotonic rise in ratio is briefly interrupted about 06:55 UT, an effect possibly related to the change in propagation conditions inferred in a companion paper [4].

With the aid of NM64 and bare counter response functions provided by Stoker [5], we can derive quantitative information on the GLE particle spectrum and its evolution. We modeled the spectrum as a power law in rigidity, $P^{-\gamma}$ where P is rigidity and γ is spectral index, and the results can be read on the inset "γ" scale on the left hand part of Figure 2b. Asymptotically, the spectral index approaches a value $\gamma \sim 5$, which is quite typical for GLEs[3].

Figure 2. (a) Count rate of NM64 and polar bare neutron counters at South Pole during the January 20, 2005 GLE, expressed as a percentage of pre-event background. These data have now been normalized to sea level using two attenuation lengths [6], and hence display a somewhat smaller increase than that shown in Figure 1 or Table 1. (b) Ratio of polar bare to NM64, together with implied spectral index γ for an assumed power law in rigidity.

3.2 Multiplicity Method

For a number of years we have conducted an annual latitude survey with a portable monitor aboard a U.S. Coast Guard icebreaker. At the time of the January 20, 2005 GLE, this instrument was in McMurdo Sound and hence recorded essentially the same primary flux as the stationary monitor at McMurdo. Unlike the stationary monitor, however, the survey instrument is equipped with special circuitry to record the distribution of elapsed times δt between successive counts in a single detector tube. For further details of this instrumentation and its use for determining cosmic ray spectra, see Bieber et al. [7].

Figure 3 displays δt distributions for an hour preceding the GLE (i.e., for a pure Galactic spectrum) and for an hour that includes the peak of the GLE. Only the first 12 δt values in each second are accumulated in the distribution. Hence the majority of δt values are discarded during the high count rate interval of the GLE peak, but the values that are recorded should represent an unbiased sample of neutron multiplicities. Multiplicity distributions are accumulated over 1 hour. The accumulation time interval is governed by the cpu clock and hence does not generally start at the beginning of a UT hour.

During quiet periods the Galactic δt distribution comprises two populations. For time intervals above ~2 ms, the distribution is a flat, smooth exponential representing single uncorrelated counts with the slope corresponding to the count rate. For time intervals less than ~2 ms, there is an additional sharp spike
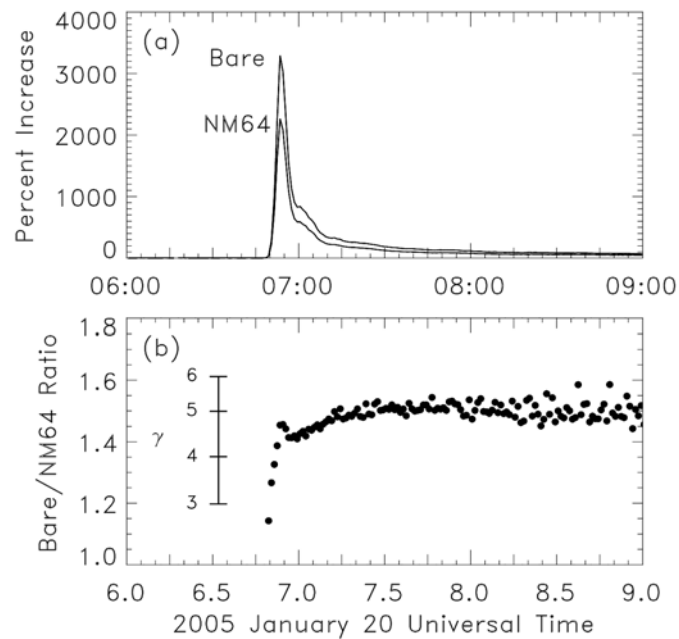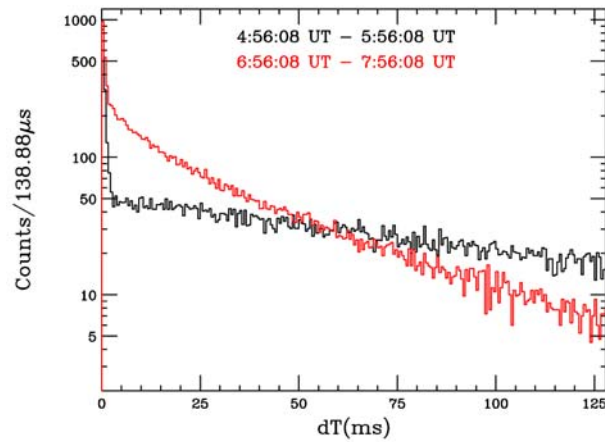
Figure 3. Histogram of time intervals between successive neutron counts, as measured by special instrumentation operated during the 2004-2005 Bartol/Tasmania latitude survey. The black (flatter) curve represents a Galactic spectrum, while the red curve includes the peak of the GLE. By modeling these time histograms, we hope to gain new information on the spectrum of the GLE.

representing multiplicity events, in which multiple evaporation neutrons are counted from a single incident particle. As shown in Figure 3, the Galactic distribution (black curve) clearly reveals these features.

The GLE distribution (red curve), however, displays a number of differences. First, the number of uncorrelated counts has increased relative to the multiplicity spike, because the solar particles have a lower energy on average than Galactic cosmic rays. Second, the GLE distribution displays a different slope in the uncorrelated region, owing to the higher count rate. Third, the GLE distribution deviates from a pure exponential below 50 ms reflecting rapidly changing count rates. In future work, we plan to model these differences with our simulation [7], thereby gaining new information on the energy spectrum of this event.

3. Summary

The largest GLE in almost half a century occurred January 20, 2005. Analyzing this event with modern instrumentation and methods affords a wonderful opportunity for studying relativistic solar particle events with unprecedented precision. This paper has focused on the basic station data, as well as the spectrum of the event. For modeling and discussion of interplanetary transport, see the companion article by Sáiz et al. [4].

4. Acknowledgements

References

[1] P. Meyer et al., Phys. Rev., 104, 768 (1956).
[2] S. E. Forbush, Phys. Rev., 70, 771 (1946).
[3] S. P. Duggal, Rev. Geophys. Space Phys., 17, 1021 (1979).
[4] A. Sáiz et al., 29th ICRC (this conference), paper tha-saiz-abs1-sh15-poster (2005).
[5] P. H. Stoker, 19th ICRC, La Jolla, 4, 114 (1985).
[6] K.G. McCracken, J. Geophys. Res., 67, 423 (1962).
[7] J. W. Bieber et al., J. Geophys. Res., 109, A12106, doi:10.1029/2004JA010493 (2004).