FINAL REPORT
NAG5-8011

Ground-Level Solar Cosmic Ray Data from Solar Cycle 19
Period of Performance: 1 January 1999 - 30 March 2002

Submitted by
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BACKGROUND

The purpose of this grant was to locate, catalog, and assemble, in standard computer format, ground-level solar cosmic ray data acquired by cosmic ray detectors for selected events in the 19th solar cycle. The events for which we initially proposed to obtain these data were for the events of 23 February 1956, 4 May 1960, 12 and 15 November 1960 and 18 and 20 July 1961. These were the largest events of the 19th solar cycle. However, a severe (more than 50%) reduction in the requested funding, required the work effort be limited to neutron monitor data for the 23 February 1956 event and the three major events in 1960.

The initial proposal was a joint investigation with Dr. K. Roger Pyle of the University of Chicago. During the time that the proposal was being evaluated, Dr. Pyle re-located from the University of Chicago to the Bartol Research Institute at the University of Delaware. Eventually two grants were awarded: one to the University of Alabama in Huntsville (Grant NAG5-8011) and the second to the Bartol Research Institute (Grant NAG5-8014).

The Grant awards were for the two-year period 1 January 1999 to 31 December 2000. Both the Bartol Institute and the University of Alabama requested no-cost extensions for one year. The University of Alabama completion date was moved to 31 March 2002.

DATA COLLECTION EFFORTS

The large relativistic solar proton events that occurred during the 22nd solar cycle stimulated renewed interest in the equally large and even larger events that occurred during the 19th solar cycle. These events of the 19th solar cycle are some of the largest peak flux and solar proton fluence events in modern time, and they have not been well modeled by contemporary techniques primarily because of the large uncertainties in the flux, fluence and spectral characteristics of these events and because much of the data are not readily available. Cosmic radiation data during the 19th solar cycle were circulated primarily between the organizations and principal investigators operating cosmic ray detectors. While bi-hourly and hourly cosmic radiation data were archived at the World Data Centers starting with the IGY in July 1957, there was no uniform format for reporting and archiving major transient variations such as the ground-level cosmic ray enhancements (GLEs) associated with major solar activity.

Recognizing that these unusual events are important to our understanding of solar processes and the interplanetary propagation of these particles from the sun to the earth, efforts were initiated in 1984

(Shea et al., 1985; Shea et al., 1987) to define a standardized format for archiving past data and for reporting new events. This effort resulted in a much more orderly transmittal and ultimate availability of the GLE data for the 22^{nd} solar cycle as documented by Gentile (1993). This database is now archived at the Australian Antarctic Division in Kingston, Tasmania (Duldig and Watts, 2001).

However, the problem remained of how to obtain the ground-level enhancement data from neutron monitors for earlier solar cycles, particularly those data that were exchanged and stored by researchers. The NASA funded effort was for the purpose of locating, cataloging and assembling selected sets of these data in the standard computer format.

Data Records Searched

We initially contacted many of the groups where cosmic ray investigations were being conducted or groups where these measurements had been conducted during the 19^{th} solar cycle. To our dismay we found many of the original records had been destroyed. As an example, at the University of New Hampshire the original data records (from the Mt. Washington monitor and from other cosmic ray detectors) used for extensive studies of the 23 February, 4 May 1960 and November 1960 events had been discarded. We also learned that the extensive data archives at the Deep River, Canada, cosmic ray laboratory had been discarded shortly after the death of Dr. Hugh Carmichael. Other inquiries to institutions that had once operated neutron monitors but had since terminated the operations were mostly unsuccessful in locating original short-time interval data records, as many of the records had been discarded during the previous decade (i.e. before renewed interest in the 22^{nd} solar cycle). Thus the only data records for many of these early events are those recorded in scientific reports or, occasionally, in tables of appropriate scientific publications.

Requests to the cosmic ray community for reports of original data records were generally not successful although a few miscellaneous records were located and acquired for the database. The notable exceptions to this loss of data were the archives retained at the University of Chicago (under Professor John A. Simpson prior to his death), the Bartol Research Institute, the University of Bern, Switzerland, and the University of Tasmania, Australia. All of these organizations have had cosmic radiation research programs starting prior to the IGY and continuing to the present time. Searches were then conducted at each of these locations. Each of these organizations have had active cosmic radiation programs since the IGY, and many individuals associated with these organizations have conducted various studies of ground-level enhancements. The GLE data from these searches were combined with other GLE data previously acquired by the principal investigator, and were then put into the standard GLE format.

The event of 23 February 1956 was of particular importance. In 50 years of cosmic radiation monitoring by neutron monitors there have been only two events where significant solar protons have been recorded by neutron monitors, ionization chambers and muon telescopes: 23 February 1956 (GLE No. 5) and 29 September 1989 (GLE No. 42). While not part of this data effort, we have noted the availability of the ionization chamber and muon telescope data for the 23 February 1956 events. In a literature search we found that during the 23 February 1956 event the following were operational: 15 neutron monitors, 23 muon telescopes, and 16 ionization chambers. The energy of the solar protons accelerated in this event was well above 17 GeV; hence increases were recorded at all ground-based cosmic ray detectors although anisotropies resulted in different increases recorded at stations with similar geomagnetic coordinates. We have been successful in obtaining the data from 11 of the neutron monitors operating during this event. Figure 1 displays some of the data from neutron monitors during the event of 23 February 1956.

GLE No. 10	12 November 1960
GLE No. 11	15 November 1960
GLE No. 12	20 November 1960

Each directory on the CDROM contains several files of cosmic radiation data recorded by neutron monitors during the time period of the ground-level enhancement. Since a "null" result is important in GLE data analyses, we have tried to include data from all stations operating at the time of the event even though not every station recorded an increase.

Ground-level enhancements have been numbered in a sequence from the initially recorded event in February 1942. (See Shea and Smart, 1993, for the list of 54 ground-level events for the period February 1942-November 1992).

While the data for GLE No. 12 was not part of this work effort, we have included whatever data were found for this event. The event on 20 November was a relatively small GLE; however, it was the third GLE associated with the same active region on the sun, and we feel these data should be included for future study of this major sequence of activity.

A "READ ME" file with a description of the data format and additional information has been included on the CDROM. This file is given in Appendix A of this report.

While attempts have been made to check the data, there are some obvious problems with some of the data sets. In most cases, the small-time interval data, when summed over the hour, does not agree with the hourly data. This is the result, primarily of the dead times in the recording devices or long-term correction factors that have been applied to the hourly data but not to the short term interval data. Timing errors associated with the various clocks were also evident. Reading "pips" from analog charts to record the counting rate at time intervals smaller than the automatic recording devices introduced other problems. Some of the problems encountered in the neutron monitor data have been documented by Gentile et al. (1990).

The GLE data from neutron monitors for the above events are now available to the scientific community. They represent our effort to assemble these data into a database with a common format. Over the years additional data or documentation might be found that can supplement these particular data sets, or can perhaps resolve some of the discrepancies that are present. It is hoped that resources can be found to archive the remaining data for other ground-level enhancements that have been located as a result of this effort. The ionization chamber and muon detector data for the 23 February 1956 event would be especially valuable as this was the largest ground-level enhancement since cosmic ray monitoring started in 1935.

PRESENTATIONS UNDER THIS GRANT

Two presentations were made at the International Cosmic Ray Conferences in an effort to canvas the community for missing records. The publications in the Cosmic Ray Conference proceedings are attached in Appendix B of this report.

Shea, M.A., R. Pyle, and D.F. Smart, Ground-Level Solar Cosmic Ray Data from Solar Cycle 19, 26th International Cosmic Ray Conference, Salt Lake City, Utah, USA, 17-25 August 1999. Poster Presentation.

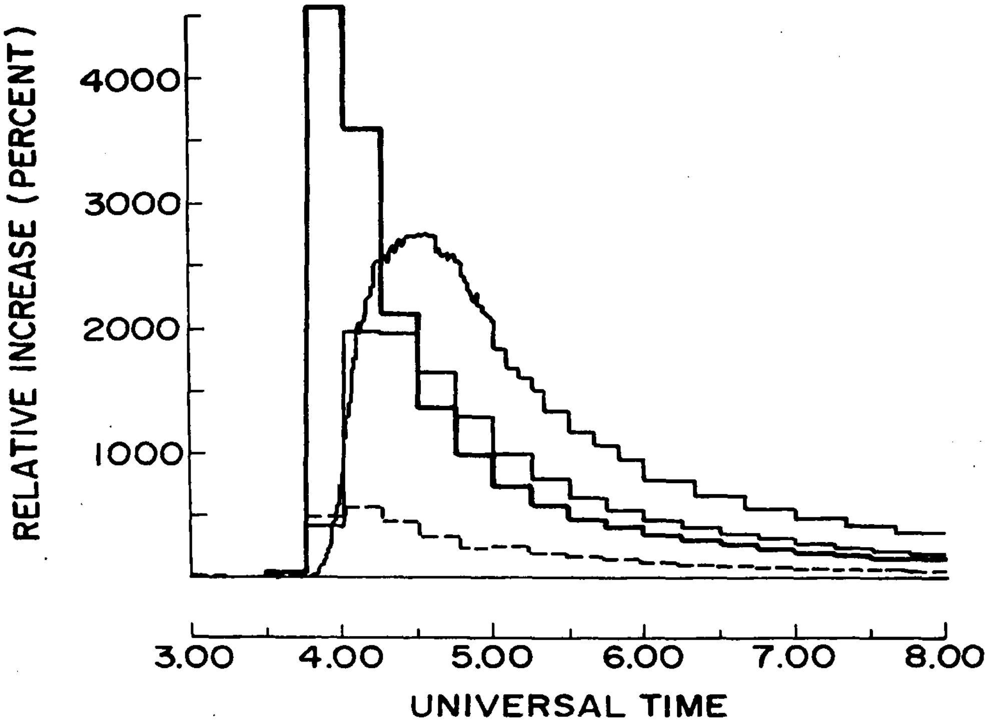

Fig. 1. Neutron monitor observations of the 23 February 1956 high-energy solar proton event. The maximum increases are: Leeds, UK (4581% as indicated by the heavy line); Ottawa; Canada (2802%); Chicago, USA (1976% as indicated by the light line); and the USS ARNEB at Wellington Harbor, NZ (575% as indicated by the dashed line).

In addition to cataloging the data available from ionization chambers and muon telescopes for the 23 February 1956 event, we also catalogued the data we found for the other ground-level enhancements not included for archival in this effort. Should funding become available in the future, these data will also be processed and made available to the scientific community.

The data we located was in a variety of time intervals ranging from bi-hourly data (the IGY standard) to smaller time increments of 1-30 minutes. All of the records located were paper listings in a wide variety of formats. Much of the supporting documentation was missing; in some cases cryptic handwritten notes were in the margins of well-used data lists. In other cases the data were not corrected for atmospheric pressure and some of the earlier records were in local time and had to be adjusted to Universal Time for uniformity.

DATA FILES

The cosmic ray data recorded by neutron monitors during the following ground-level events are included on the attached CDROM.

GLE No. 5	23 February 1956
GLE No. 8	4 May 1960

Shea, M.A., D.F. Smart, K.R. Pyle, M.L. Duldig, and J.E. Humble, Update on the GLE Database: Solar Cycle 19, 27th International Cosmic Ray Conference, Hamburg, Germany, 7-15 August 2001. Poster Presentation.

PUBLICATIONS UNDER THIS GRANT

Shea, M.A., R. Pyle, and D.F. Smart, Ground-Level Solar Cosmic Ray Data from Solar Cycle 19, *26th International Cosmic Ray Conference, Contributed Papers*, **6**, 391-394, 1999.

Shea, M.A., D.F. Smart, K.R. Pyle, M.L. Duldig, and J.E. Humble, Update on the GLE Database; Solar Cycle 19, *27th International Cosmic Ray Conference, Contributed Papers*, **8**, 3405-3408, 2001.

REFERENCES

Duldig, M.L., and D.J. Watts, The New International GLE Database, *27th International Cosmic Ray Conference, Conference Papers*, **8**, 3409-3412, 2001.

Gentile, L.C., Relativistic Solar Proton Database for the Ground Level Enhancements during Solar Cycle 22, *J. Geophys. Res.*, **98**, 21,107-21,109, 1993.

Gentile, L.C., M.A. Shea and D.F. Smart, Problems Associated with the Cataloging of Neutron Monitor Data for Ground-Level Solar Cosmic Ray Events, *21st International Cosmic Ray Conference, Conference Papers*, **5**, 148-151, 1990.

Shea, M.A., and D.F. Smart, Solar Proton Events: History, Statistics, and Predictions, in Solar-Terrestrial Predictions Workshop-IV, 2, Edited by J. Hruska, M.A. Shea, D.F. Smart, and G. Heckman, U.S. Department of Commerce, NOAA, ERL, Boulder, Colorado, 48-70, 1993.

Shea, M.A., D.F. Smart, M. Wada, and A. Inoue, A Suggested Standardized Format for Cosmic Ray Ground-Level Event Data, *19th International Cosmic Ray Conference, Conference Papers*, **5**, 510-513, 1985.

Shea, M.A., D.F. Smart, J.E. Humble, E.O. Flückiger, L.C. Gentile, and M.R. Nichol, A Revised Standard Format for Cosmic Ray Ground-Level Event Data, *20th International Cosmic Ray Conference, Conference Papers*, **3**, 171-174, 1987.

APPENDIX A

GLE DATABASE FORMAT

The following is an explanation of the ground-level enhancement (GLE) data on the CDROM and how the files are organized.

The CDROM has been organized into individual directories for each ground-level event as follows:

Gle05	(23 February 1956 event)
Gle08	(4 May 1960 event)
Gle10	(12 November 1960 event)
Gle11	(15 November 1960 event)
Gle12	(20 November 1960 event)

There are individual data files within each directory. Data file names are in the form C##NAME.DAT where C indicates a Counts Per Second/Percentage Increase file, ## represents the event number, and NAME is a four-letter abbreviation for the station name as shown in Table A1. Thus the file named C05CLMX.DAT contains the GLE data for event No. 5 (23 February 1956) recorded by the neutron monitor located at Climax, Colorado.

In addition to the individual directions, a listing of the stations and file sizes are included as text files. These are identified by the GLE number (e.g. Gle05.LST)

ORGANIZATION OF DATA FILES:

Each data file contains three or four sections: Station and Equipment Identification, Column Headers, Cosmic Ray Data, and Comments.

Station and Equipment Identification Section: The first seven lines for each data file are headers containing specific information on the neutron monitor station and the data included in the data file. The header information includes the station Latitude, Longitude, Altitude, Instrument, Standard Station Pressure in whatever units used by the principal investigator, Pressure Correction Coefficient, Pre-Increase Baseline Time Interval (date and time interval), Pre-Increase Average Counting Rate in counts/second, the time intervals for which data are available (in seconds) and scale factors. We selected the hour prior to any increase as the pre-increase baseline time interval whenever possible. Since the original data contained various scaling factors, we tried to reduce the data to counts per second in which case the scale factors are 1. (They are listed as -1 for programmatic reasons.) However, some of the scale factors that still remain on the data records are indicative of the many scale factors encountered in the data records. All data have been reduced to counts per second unless otherwise indicated. In addition when only uncorrected cosmic ray data and atmospheric pressures were available, the data were corrected for standard atmospheric pressure if the pressure correction coefficient was known.

Column Headers Section: The eighth and ninth lines are column headers and identify the fields of data that follow. These are the only two lines before the actual cosmic ray data that do not contain the station identification as the first 10 characters.

Cosmic Ray Data Section: Data start in the ninth line and continue until an end of data is indicated by an asterisk (*) in column 1. (Note that the header lines and the data lines all start with a 10-character station identification - but not the column header lines.)

Comments Section: Because the original data came from a variety of sources and from different data records, a comment file has been added at the end of many data files for relevant comments. Each line is identified by the word "Comment" as the first 7 characters. Each comment (and succeeding lines, if necessary) starts in column 12. The end of data mark is a row of asterisks (*) after the comments section. Table A2 gives the format of the data file.

Table A1

Abbreviations for Neutron Monitor Stations*

AHMD	Ahmedabad		
ALBQ	Albuquerque	MWSN	Mawson
AATA	Alma Ata - A	MCMD	McMurdo
BERK	Berkeley	MXCO	Mexico City
BUEN	Buenos Aires	MINA	Mina Aguilar
CHCL	Chacaltaya	MRNY	Mirny
CHGO	Chicago	MOSC	Moscow
CHUR	Churchill	MTNB	Mt. Norikura (Event No. 5 only)
CLMX	Climax	MTNR	Mt. Norikura
COLL	College	MTWS	Mt. Washington
DPRV	Deep River	MTWL	Mt. Wellington
DRHM	Durham	MNCH	Munich
ELSW	Ellsworth	MRMN	Murmansk
HEIS	Heiss Island	NERA	Nera
HRMS	Hermanus	OTWA	Ottawa
HRST	Herstmonceux	OTTN	Ottawa - new (Event No. 5 only)
HBRT	Hobart	OTTO	Ottawa - old (Event No. 5 only)
HUAN	Huancayo	PICD	Pic du Midi
JUNG	Jungfraujoch	PRAG	Prague
KERG	Kerguelen Is.	RSLT	Resolute
KIEL	Kiel	RIOD	Rio de Janeiro
KODI	Kodaikanal	ROME	Rome
LAE	Lae	SACP	Sacramento Peak
LEED	Leeds	SLPM	Sulphur Mt.
LIML	Limeil	SYWA	Syowa
LINC	Lincoln	THUL	Thule
LIND	Lindau	UPPS	Uppsala
LNDN	London	USHU	Ushuaia
MKPU	Makapuu	YKTK	Yakutsk
MKER	Makerere	ZUGS	Zugspitze
		BOAT	USS Arneb (Event No. 5 only)

*The station codes are not case sensitive.

Table A2

Format of the Neutron Monitor Data File

There are 10 fields of data; each field is followed by a blank space to separate the fields.

1. Station identification (10 characters)
2. Year, month, day (yymmdd) (6 characters)
3. Number of seconds in the data interval (4 characters).
4. Time interval (in Universal Time) with the time at the start of the interval in hours, minutes and seconds, a hyphen, and the time at the end of the interval, in hours, minutes and seconds (13 characters)
5. A two-character field labeled "Code" where "T" is for timing accuracy and "D" is a data code. The codes are the following:

   Timing Codes:

0	Time accurate to the nearest minute
1	Time accurate to the nearest second
2	Time accurate to the nearest 10 seconds
3	Time accurate to the nearest 30 seconds
7	Time uncertainty greater than 1 minute and less than five minutes.
8	Time uncertainty greater than or equal to five minutes
9	Probable time error of undetermined amount in source data; approximate time adjustment has been made.

   Data Codes:

0	Data record includes uncorrected cosmic ray data, measured atmospheric pressure, and cosmic ray data corrected for atmospheric pressure.
1	Data record includes uncorrected cosmic ray data, interpolated atmospheric pressure, and cosmic ray data corrected for atmospheric pressure.
2	Corrected cosmic ray data only; no other data available.
3	Uncorrected cosmic ray data only; no other data available.
4	Corrected and uncorrected cosmic ray data only. (No atmospheric pressure given for the observation period or insufficient information for pressure interpolation.)
5	Percentage increase only. (The baseline time intervals may be different from the hour before the increase.)
6	Cosmic ray data do not exist (e.g. due to calibration, equipment failure, etc.)
9	Existence of cosmic ray data unknown.

6. Uncorrected counting rate in counts per second (10 characters, F10.2)
7. Barometric pressure (F7.2 if pressure is in centimeters or inches; F6.1, 1X if pressure is in millimeters or millibars.
8. Counting rate in counts per second, corrected for atmospheric pressure (9 characters, F9.2)
9. Percentage increase above the pre-increase average counting rate determined from the baseline time interval with no blank space at the end (F6.1).

The following tables list the data files in each directory. Additional comments have been provided as necessary. It is important to note that not every station in each set actually recorded an increase. Since "no increase" reported is of value for studies of anisotropy, spectrum and maximum energy present, data for as many stations as available at the present time were included in the data files.

Table A3

Directory of GLE 05 (23 February 1956)

```
  12 File(s)        111,905 bytes

  3,157 C05ALBQ.DAT
  5,194 C05BOAT.DAT
 12,614 C05CHGO.DAT
 11,023 C05CLMX.DAT
  7,626 C05HUAN.DAT
 13,763 C05LEED.DAT
  9,235 C05MTNB.DAT
  8,875 C05MTNC.DAT
  3,017 C05MXCO.DAT
 14,210 C05OTTN.DAT
 18,226 C05OTTO.DAT
  4,965 C05SACP.DAT
```

Notes:

1. There are two files for Mt. Norikura: MTNB and MTNC. The file MTNB uses the time interval from 013000-033000 UT as the baseline. Bi-hourly data was the common interval of time for reporting cosmic ray data prior to and through the IGY period. The other file uses the period 020000-030000 UT as the baseline from which the percentage increase was calculated.

2. There are two files from Ottawa, Canada. At that time the Canadians were operating two IGY-type monitors, designated as Ottawa old (OTTO) and Ottawa new (OTTN). To the best of our knowledge the "OLD" monitor was non-standard and the "NEW" monitor was a standard IGY type monitor.

Table A4

Directory of GLE08 (4 May 1960)

```
   41 File(s)       167,602 bytes

3,525 C08AHMD.DAT
5,526 C08BERK.DAT
4,448 C08BUEN.DAT
2,600 C08CHGO.DAT
7,297 C08CHUR.DAT
4,602 C08CLMX.DAT
4,448 C08COLL.DAT
8,221 C08DPRV.DAT
3,909 C08ELSW.DAT
2,677 C08HEIS.DAT
3,293 C08HRMS.DAT
3,447 C08HRST.DAT
4,448 C08HUAN.DAT
4,448 C08JUNG.DAT
2,600 C08KERG.DAT
2,600 C08KODI.DAT
4,449 C08LAE.DAT
4,294 C08LEED.DAT
1,676 C08LIML.DAT
2,600 C08LINC.DAT
4,833 C08LIND.DAT
4,448 C08MINA.DAT
2,600 C08MKER.DAT
2,600 C08MNCH.DAT
2,677 C08MRMN.DAT
2,600 C08MTNR.DAT
7,605 C08MTWS.DAT
2,600 C08NERA.DAT
7,066 C08OTWA.DAT
2,754 C08PICD.DAT
2,600 C08PRAG.DAT
2,754 C08RIOD.DAT
4,756 C08ROME.DAT
6,527 C08RSLT.DAT
4,448 C08SACP.DAT
5,911 C08SLPM.DAT
2,619 C08SYWA.DAT
5,215 C08THUL.DAT
4,448 C08UPPS.DAT
2,600 C08YKTK.DAT
4,833 C08ZUGS.DAT
```

Table A5

Directory of GLE 10 (12 November 1960)

```
     52 File(s)        509,079 bytes

  3,457 C10aata.dat
  6,299 C10AHMD.DAT
  3,458 C10berk.dat
  8,381 C10buen.dat
 11,817 C10chcl.dat
  9,934 C10chgo.dat
  6,363 C10chur.dat
 11,782 C10clmx.dat
 10,237 C10coll.dat
 11,781 C10dprv.dat
  6,245 C10drhm.dat
 63,590 C10elsw.dat
  6,279 C10hbrt.dat
  3,624 C10heis.dat
  9,933 C10hrms.dat
 11,778 C10huan.dat
 11,734 C10jung.dat
 10,072 C10KERG.DAT
  3,458 C10kiel.dat
  6,266 C10kodi.dat
  6,299 C10LAE.DAT
 12,828 C10leed.dat
  5,373 C10liml.dat
  3,639 C10linc.dat
  9,934 C10lind.dat
 10,494 C10lndn.dat
  9,900 C10mcmd.dat
 11,775 C10mina.dat
  3,458 C10mkpu.dat
  9,934 C10mnch.dat
  3,652 C10mosc.dat
  3,575 C10mrmn.dat
  6,229 C10mrny.dat
  3,458 C10mtnr.dat
 31,640 C10mtwl.dat
 14,708 C10mtws.dat
 29,796 C10mwsn.dat
 11,781 C10nera.dat
  6,347 C10otwa.dat
  9,934 C10picd.dat
  9,934 C10prag.dat
  6,230 C10riod.dat
  3,458 C10rome.dat
  6,229 C10rslt.dat
  6,214 C10sacp.dat
  3,457 C10slpm.dat
  3,545 C10SYWA.DAT
 11,710 C10thul.dat
 17,836 C10upps.dat
 12,193 C10ushu.dat
  3,573 C10yktk.dat
  3,458 C10zugs.dat
```

Table A6

Directory of GLE11 (15 November 1960)

```
     52 File(s)        404,743 bytes

  3,457 C11aata.dat
  6,299 C11AHMD.DAT
  3,457 C11berk.dat
  8,363 C11buen.dat
 11,550 C11chcl.dat
  7,837 C11chgo.dat
  6,229 C11chur.dat
 10,161 C11clmx.dat
 10,207 C11coll.dat
  3,457 C11dprv.dat
  6,278 C11drhm.dat
 24,466 C11elsw.dat
  6,280 C11hbrt.dat
  3,861 C11heis.dat
  9,995 C11HRMS.DAT
 10,417 C11huan.dat
 11,758 C11jung.dat
  9,607 C11kerg.dat
  3,458 C11kiel.dat
  6,223 C11kodi.dat
  6,453 C11LAE.DAT
 14,194 C11leed.dat
  3,213 C11liml.dat
  3,759 C11linc.dat
  9,934 C11lind.dat
  6,301 C11lndn.dat
  9,567 C11mcmd.dat
 11,551 C11mina.dat
  3,517 C11mkpu.dat
  9,934 C11mnch.dat
  3,752 C11mosc.dat
  3,457 C11mrmn.dat
  6,229 C11mrny.dat
  3,458 C11mtnr.dat
 15,578 C11mtwl.dat
  6,368 C11mtws.dat
 19,831 C11mwsn.dat
 11,550 C11nera.dat
  6,288 C11otwa.dat
  6,697 C11picd.dat
  9,395 C11prag.dat
  6,230 C11riod.dat
  3,458 C11rome.dat
  6,227 C11rslt.dat
  6,233 C11sacp.dat
  3,457 C11slpm.dat
  3,545 C11SYWA.DAT
  7,859 C11thul.dat
 14,294 C11upps.dat
 12,021 C11ushu.dat
  3,575 C11yktk.dat
  3,458 C11zugs.dat
```

Table A7

Directory of GLE12 (20 November 1960)

46 File(s)	216,086 bytes
3,687	C12aata.dat
4,092	C12ahmd.dat
3,446	C12berk.dat
6,289	C12buen.dat
3,458	C12chgo.dat
6,229	C12chur.dat
6,227	C12clmx.dat
7,541	C12coll.dat
3,457	C12dprv.dat
10,244	C12elsw.dat
3,919	C12heis.dat
3,457	C12hrms.dat
6,230	C12huan.dat
6,194	C12jung.dat
3,458	C12kerg.dat
3,455	C12kiel.dat
3,584	C12kodi.dat
3,458	C12leed.dat
2,054	C12liml.dat
3,458	C12linc.dat
3,458	C12lind.dat
3,516	C12lndn.dat
6,230	C12mcmd.dat
6,230	C12mina.dat
3,446	C12mkpu.dat
3,458	C12mnch.dat
3,644	C12mosc.dat
3,457	C12mrmn.dat
3,458	C12mtnr.dat
6,230	C12mtwl.dat
6,407	C12mtws.dat
6,361	C12mwsn.dat
6,229	C12nera.dat
6,229	C12otwa.dat
3,458	C12picd.dat
3,458	C12prag.dat
3,458	C12rome.dat
6,229	C12rslt.dat
6,198	C12sacp.dat
3,457	C12slpm.dat
3,451	C12sywa.dat
3,458	C12thul.dat
6,229	C12upps.dat
7,249	C12ushu.dat
3,693	C12yktk.dat
3,458	C12zugs.dat

APPENDIX B

Publications

The following publications were the results of efforts under this Grant:

Shea, M.A., R. Pyle, and D.F. Smart, Ground-Level Solar Cosmic Ray Data from Solar Cycle 19, *26th International Cosmic Ray Conference, Contributed Papers*, **6**, 391-394, 1999.

Shea, M.A., D.F. Smart, K.R. Pyle, M.L. Duldig, and J.E. Humble, Update on the GLE Database; Solar Cycle 19, *27th International Cosmic Ray Conference, Contributed Papers*, **8**, 3405-3408, 2001.

Copies of these publications are attached.

26th International Cosmic Ray Conference, Conference Papers, **6**, 391-394, 1999.

Ground-Level Solar Cosmic Ray Data from Solar Cycle 19

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Abstract

We have recently begun a two-year project to compile ground-based cosmic ray detector data for the major ground-level proton events of Solar Cycle 19. Many of these unique datasets have been published, but much small-time-resolution data exist in uncatalogued notebooks, etc.

The largest events (2/23/56, 5/4/60, and 11/12&15/60) will be catalogued, verified and deposited in the data center. Many of these records are in primitive form, (strip charts, film, graphs); much of the data was used for specific analyses at the time. The major 1961 events will be catalogued, but further verification will be postponed, pending future funding.

It is important to compile these data since they have not been adequately modeled using modern techniques, because of a lack of a reliable database. Our primary goal is to compile such a comprehensive database, allowing new analyses of these events. This project is funded by grants from NASA's Data Restoration Program.

1 Introduction:

We have recently started a two-year project to compile neutron monitor data for the major ground-level proton events (GLEs) of Solar Cycle 19. While a few of these unique datasets have been published, most of the data, particularly data for small time intervals, exist in uncataloged notebooks and private data collections. Although much of the data was used for specific analysis at the time of the events, many of these records have been stored in relative primitive form such as strip charts, film, graphs, etc.

The relativistic solar proton events of the 19th solar cycle were not only the first GLEs recorded by neutron monitors but also some of the largest GLEs since 1955. These events have not been adequately modeled using modern techniques and theories because of the unavailability of a reliable and easily accessible database. The goal of this project is to compile the data for some of the major GLEs of the 19th solar cycle, allowing new analyses of these events. This paper presents an overview and status report of this project.

2 Identification of Events

Ten ground-level events were identified by neutron monitors during the 19th solar cycle. The GLE of 23 February 1956, with an increase of over 4000% recorded at Leeds, UK, remains the largest GLE since the advent of neutron monitors. In addition to being some of the largest events since 1955, the events exhibited a variety of time-intensity profiles from classic "fast rising-rapid decay" to extremely complex particle behavior. These events also occurred during both quiet and extremely disturbed interplanetary and geomagnetic conditions. Table 1 lists the 10 GLEs and the approximate increases recorded by high latitude neutron monitors.

3 Cataloging Procedures

Neutron monitor data records are being obtained and examined to determine what data exist for the events of 23 February 1956, 4 May 1960, and the three events in November 1960. We are particularly interested in small time interval data which can be utilized to identify the times of onset and maximum intensity as well as unusual flux variations. Table 2 lists the data we have already located for the five major events. Very few neutron monitors were operating during the 23 February 1956 event, and the data are relatively limited. Many more neutron monitors were in operation during 1960 although, at the present time, we do not have small time-interval data for many of these stations. In several cases bi-hourly data are the only records we have located. Small-time intervals, for the purposes of this table, include intervals from 1 minute to 30 minutes. Much of the earlier recording devices acquired data in 15-minute intervals although, in some cases, strip charts were available for smaller intervals.

Our plans are to codify as much as these data as possible into the standard GLE format (Gentile, 1993). The data records will not be as complete as those acquired during the events of the 22nd solar cycle since some parameters such as barometric pressure and uncorrected data have been lost. Nevertheless, this effort is expected to produce a useful and more easily accessible database for studies of these unusual events. Throughout this process we also expect to acquire information on data availability for the remaining five GLEs during solar cycle 19 in addition to information on muon and ionization data for the 23 February 1956 event. Only two events since 1955 (23 February 1956 and 29 September 1989) have significant increases recorded by muon monitors and ionization detectors. Unfortunately, funding resources do not permit the cataloging of these data at this time.

4 Specific Request to the Cosmic Ray Community:

We have not yet been able to acquire data from all neutron monitors in operation during the time periods of interest. Cosmic ray scientists are requested to search their laboratory notebooks and personal archives to aid us in this project. In addition to the small time-interval data we need for this project, there are some stations (e.g. Tbilisi) for which we have no data at all, even though it was in operation in 1960. Copies of data records can be sent to any of the above authors.

5 Summary:

Neutron monitor data are being acquired for the major ground-level events that occurred in the 19th solar cycle. Our primary goal is to compile a comprehensive database for new analyses of these unique solar proton events. The database will be deposited in the World Data Centers at which time they will be available to the scientific community.

6 Acknowledgements:

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Table 1

Date	Increase (%)	Station
23 Feb 1956	4554	Leeds, UK
31 Aug 1956	3	Chicago, USA
17 Jul 1959	10	Resolute, Canada
4 May 1960	290	Churchill, Canada
3 Sep 1960	4	Murmansk, Russia
12 Nov 1960	135	Thule, Greenland
15 Nov 1960	160	Mawson, Antarctica
20 Nov 1960	8	McMurdo, Antarctica
18 Jul 1961	24	Thule, Greenland
20 Jul 1961	7	Ottawa, Canada

Table 2. Data Received for Five Major GLE's in Solar Cycle 19

Station	**23 Feb 1956**	**4 May 1960**	**12 Nov 1960**	**15 Nov 1960**	**20 Nov 1960**
Ahmedabad	-----	BH	H	H	BH
Albuquerque	H, ST	-----	-----	-----	-----
Alma Ata - A	-----	-----	BH	BH	BH
Bergen	-----	H	H	H	H
Berkeley	-----	ST*	BH	BH	BH
Buenos Aires	-----		H, ST	H, ST	H
Chacaltaya	-----	-----	H, ST	H, ST	H
Chicago	H, ST	BH	BH, ST	BH, ST	BH
Churchill	-----	H, ST	H	H	H
Climax	H, ST	H	H, ST	H, ST	H
College	-----	H, ST	BH, ST	BH, ST	BH, ST
Deep River	-----	H, ST	H, ST	BH	BH
Durham			BH, H	BH	
Ellsworth	-----	ST*	H, ST	BH, ST	H, ST
Halle	-----	BH	BH	BH	BH
Heiss Island	-----	BH	BH	BH	BH
Hermanus	-----	BH, ST	BH, ST	BH, ST	BH
Herstmonceux	-----	BH, ST	-----	-----	-----
Hobart	-----	-----	H	H	
Huancayo	H, ST	H	H, ST	H, ST	H
Irkutsk	-----	BH	BH	BH	BH
Jungfraujoch	-----	H	H, ST	H, ST	H
Kerguelen Is.	-----	BH	BH, ST	BH, ST	BH
Kiel	-----	BH	BH	BH	BH
Kodaikanal	-----	BH	BH	BH	BH
Lae	-----	H	H	H	H
Leeds	H, ST	BH, ST	BH, ST	BH, ST	BH
Limeil	-----	**	**, ST	**, ST	**
Lincoln	-----	BH	BH	BH, ST	BH
Lindau	-----	BH, ST	BH, ST	BH, ST	BH
Lomnicky Stit	-----	BH	-----	-----	-----

London	-----	-----	BH, ST	BH, ST	BH
Makapuu	-----		BH	BH	BH
Makerere	-----	BH			
Mawson	-----	H, ST	H, ST	H, ST	H, ST
McMurdo	-----	H	H, ST	H, ST	H
Mexico City	ST*		ST	H, ST	
Mina Aguilar	-----	H	H, ST	H, ST	H
Mirny	-----		H	H	BH
Moscow	-----	BH	BH	BH	BH
Mt. Norikura	BH	BH	BH	BH	BH
Mt. Washington		H, ST	H, ST	H	H
Mt. Wellington	-----	H, ST	H, ST	H, ST	H
Munich	-----	BH	BH, ST	BH, ST	BH
Murmansk	-----	BH	BH	BH	BH
Nera	-----	BH	H, ST	H, ST	H
Ottawa-1	H, ST	H, ST	H	H	H
Ottawa-2	H, ST				
Pic du Midi	-----	BH	BH, ST	BH, ST	BH
Prague	-----	BH	BH, ST	BH, ST	BH
Resolute	-----	H, ST	H	H	H
Rio de Janeiro	-----	BH	H	H	H
Rome	-----	BH, ST	BH	BH	BH
Sacramento Peak	ST*	H	H, ST	H	H
Schauinsland	-----	H	H	H	H
Sulphur Mt.	-----	BH, ST	BH	BH	BH
Syowa	-----	BH, ST	BH	BH	BH
Thule	-----	BH, ST	H, ST	BH, ST	BH
Uppsala	-----	H	H, ST	H, ST	H
Ushuaia	-----		H, ST	H, ST	H
Yakutsk	-----	BH	BH	BH	BH
Zugspitze	-----	BH, ST	BH	BH	BH
USS Arneb	ST	-----	-----	-----	-----

Codes:

BH = Bihourly data

H = Hourly data

ST = Small-time interval data

* = Extremely limited data

** 4-hourly data.

Notes: The dashed line indicates that the station was not in operation.

Small time-interval data are from 1-minute to 30-minute intervals.

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Update on the GLE database: solar cycle 19

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Abstract. An effort has been underway to collect, evaluate, and archive the neutron monitor data for the major ground-level events of solar cycle 19. While numerical records in various forms have been located for the four major events: 23 February 1956, 4 May 1960, 12 November 1960 and 15 November 1960, some of the data are difficult to interpret. Questions have arisen, primarily with respect to the event on 4 May 1960. In addition we present a list of stations for which data are still being sort.

1 Introduction

At the 26th International Cosmic Ray Conference we presented a paper on a project to compile ground-based cosmic ray detector data for the major ground-level proton events of Solar Cycle 19 (Shea et al., 1999). A list of events and station data already acquired was included in that publication. At the same time we requested members of the cosmic ray community to search their laboratory notebooks and personal archives to aid us in this task. In this paper we present a report on the progress of this project.

2 Data Acquired

The work over the past two years has concentrated on acquiring, sorting, and archiving, in standard GLE format (Gentile, 1993), the data for the 4 May 1960 event. This was a major ground-level enhancement with increases greater than 200% recorded by neutron monitors in North America. The particle increase was extremely anisotropic (associated flare position 90° West) with much smaller increases recorded by European monitors. Table 1 presents a summary of information gathered from the various records that have been examined.

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3 Discussion

An inspection of Table 1 shows the following:
1. Polar and mid-latitude stations recorded this event. Equatorial stations did not record the event.
2. The onset times varied considerably. The onset time from the Zugspitze data appears to indicate a mistake of an hour in the printed data.
3. Several stations (i.e. Heiss Island, Munich, and Yakutsk) have data missing at the time of the event. The increase in counting rate may have been considered to be noisy data and been removed before the data were distributed.
4. Data in small time intervals is extremely important for analyses of these events. However, even the large interval data are useful for an overall evaluation of the event.

From investigators we know that the late onset time recorded by the College monitor was suspect, and it was believed by many that there was a clock timing error. These data must be compared with other neutron monitor data, and analyzed with modern techniques such as described by Cramp et al. (1997) before some of the discrepancies can be resolved.

4 Request to the Cosmic Ray Community

Table 1 is an example of what we would like to prepare for the three other large relativistic solar proton events of the 19th solar cycle. Obviously we would like to have smaller time interval data than the bi-hourly or hourly data we presently have for many of the neutron monitors. However, we recognize that many stations distributed and/or archived their data in the bi-hourly time intervals recommended during the IGY. While smaller time interval data may have been recorded at these stations, these data generally were circulated within the cosmic ray community and usually only upon receipt of a special request. These are the data sets we hope will be found in old notebooks or personal records.

Table 1. Summary of 4 May 1960 Ground-Level Event from neutron monitor data

Station	Time Interval (Min)	Onset	Time of Maximum	Percent Increase (Note 1)	Additional Comments
Ahmedabad	7200				No increase
Berkeley	120	1032-1034	1038-1040	36	
Buenos Aires	3600				No increase
Chicago	7200		1000-1200	26	
Churchill	60	1025-1030	1036-1037	270	
Climax	3600		1000-1100	42	
College	900	1040-1055	1040-1055	18	
Deep River	60	1025-1030	1039-1041	210	
Ellsworth	900	1030-1045	1030-1045	110	
Heiss Island	7200				Note 2
Hermanus	900	1030-1045	1030-1045	8	Note 3
Herstmonceux	600	1040-1050	1040-1050	4	
Huancayo	3600				No increase
Jungfraujoch	3600		1000-1100	3	
Kerguelen	7200		1200-1400	5	
Kodaikanal	7200				No increase
Lae	3600				No increase
Leeds	900	1030-1045	1100-1115	8	Note 3
Limeil	7200				Note 4
Lincoln	7200		1000-1200	27	
Lindau	900	1015-1030	1045-1100	11	Note 3
Mina Aguilar	3600				No increase
Makerere	7200				No increase
Mawson	600	1035-1040	1040-1045	20	
Munich	7200				Note 2
Murmansk	7200				Note 4
Mt. Norikura	7200				No increase
Mt. Washington	120	1025-1030	1040-1042	211	
Nera	7200		1000-1200	4	
Ottawa-1	60	1030-1032	1039-1040	185	
Ottawa-2	60	1030-1032	1039-1040	182	
Pic du Midi	7200				Note 4
Prague	7200				Note 4
Rio de Janeiro	7200				No increase
Rome	900				No increase
Resolute	600	1035-1040	1045-1050	42	
Sacramento Peak	3600		1000-1100	10	
Sulphur Mt.	60	1025-1030	1041-1042	342	
Syowa	7200		1000-1200	22	
Thule	120	1030-1032	1042-1048	134	Note 3
Uppsala	3600		1100-1200	4	
Yakutsk	7200				Note 2
Zugspitze	900	1145-1200	1215-1230	15	Note 3

Note 1: Increases have not been corrected to sea level
Note 2: Data missing at the time of the event
Note 3: Scaling factor problem (or dead time correction) needed to reconcile hourly with short time data.
Note 4: Poor statistics make it difficult to discern event.

5 Data Requested

5.1 Event of 23 February 1956

From Dorman (1957) we know that cosmic ray data for the 23 February 1956 event were recorded by several neutron monitors. We do not have any data for the following stations for this event:

- Berkeley
- Durham
- Gottingen
- Mt. Washington
- Stockholm
- Weissenau

Professor Dorman also published many graphs of ionization chamber data for this same event. We would be extremely grateful to anyone who can provide the original data as we can then compare the high-energy characteristics of this event with the 29 September 1989 relativistic solar proton event.

5.2 Event of 4 May 1960

We are looking for data, in as small a time interval as available, from the following stations:

- Buenos Aires
- Durham
- Ellsworth
- Makapuu Point
- Mexico City
- Mirny
- Ushuaia

While we believe that low latitude stations such as Buenos Aires and Makapuu Point would not have recorded any increase in cosmic ray intensity, these data would supplement what is presently available in the archive. Although it appears unlikely that the Mexico City monitor would have recorded any discernible increase in cosmic ray intensity, the data from this station would be valuable in helping to establish the upper limit of the energy of the solar particles in this event.

5.3 Events of 12 and 15 November 1960

These two events were extremely unusual with substantial increases in the cosmic radiation intensity resulting from solar activity near the central meridian of the sun. The intensity-time profiles for the 12 November 1960 event were extremely complex, with the complexity attributed to the impact of an interplanetary disturbance from previous solar activity. We are looking for small time interval data from the following neutron monitors:

Ahmedabad	
Alma Ata	
Bergen	
Berkeley	
Churchill	
Deep River	(15 Nov)
Durham	
Halle	
Heiss Island	
Hobart	
Irkutsk	
Kiel	
Kodaikanal	
Lae	
Lincoln	(12 Nov)
Makapuu	
Makerere	
Mirny	
Moscow	
Mt. Washington	(15 Nov)
Murmansk	
Mt. Norikura	
Ottawa	
Resolute	
Rio de Janeiro	
Rome	
Sacramento Peak	(15 Nov)
Schauinsland	
Sulpher Mt.	
Syowa	
Yakutsk	
Zugspitze	

For a few of the stations we have small time interval data for one of the two events. When a date is shown in the above table, we are missing the detailed data for the specific event as indicated.

We recognize that many of these stations would not have recorded an increase during these November 1960 events; however, the extreme geomagnetic disturbances resulted in simultaneous decreases recorded by low latitude stations, making this an extremely interesting period for re-evaluation in light of present knowledge.

6 Summary and Conclusions

We have presented a progress report on the data acquired from neutron monitors during ground-level events of the 19th solar cycle. The assistance of the cosmic ray community is requested to help locate some of the data that we know was acquired, but we do not have in this archive. The database will be eventually deposited in the World Data Centers.

Acknowledgements

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