AD-A231 455

DTIC FILE COPY

(1)

DTIC ELECTE JAN 11 1991 S B D

REPORT DOCUMENTATION PAGE

Form Approved CMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; Distribution unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): GL-TR-90-0356	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Geophysics Laboratory; 6b OFFICE SYMBOL (If applicable): PHG	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code): Hanscom AFB, Massachusetts 01731-5000	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO 61102F; PROJECT NO 2311; TASK NO G4; WORK UNIT ACCESSION NO 01

11 TITLE (Include Security Classification)
Thirty Years of Solar Proton Events

12 PERSONAL AUTHOR(S)
D.F. Smart, M.A. Shea

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Reprint	FROM ____ TO ____	1990 December 31	4

16 SUPPLEMENTARY NOTATION
Reprinted from 21st International Cosmic Ray Conference, Conference Papers, 5 1-4, 1990

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB GROUP	Solar protons, Solar cycle, Space environment, Ground-level events, Solar proton fluence

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A total of 217 significant solar proton events with a flux of over 10 particles $(cm^2\text{-sec-ster})^{-1}$ above 10 MeV have been observed at the earth during the past three solar cycles with at least 15% of these events containing relativistic (i.e. > 450 MeV) protons. Other than an increase in solar proton event occurrence with an increase in the sunspot cycle, no recognizable pattern could be identified between the occurrence of solar proton events and the solar cycle.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: M.A. Shea	22b TELEPHONE (Include Area Code): (617) 377-3977; 22c OFFICE SYMBOL: PHG

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

91 1 10 057

GL-TR-90-0356

Reprint from 21st International Cosmic Ray Conference, Conference Papers, 5, 1-4, 1990.

THIRTY YEARS OF SOLAR PROTON EVENTS

D. F. Smart and M. A. Shea

Geophysics Laboratory
Bedford, MA 01731 USA

Abstract

A total of 217 significant solar proton events with a flux of over 10 particles $(cm^2\text{-sec-ster})^{-1}$ above 10 MeV have been observed at the earth during the past three solar cycles with at least 15% of these events containing relativistic (i.e. > 450 MeV) protons. Other than an increase in solar proton event occurrence with an increase in the sunspot cycle, no recognizable pattern could be identified between the occurrence of solar proton events and the solar cycle.

Introduction. To study and analyze solar proton events over the past three solar cycles it is necessary to assemble a list of solar proton events that is as homogeneous as possible. Using a criterion that each event have a proton flux of over 10 particles $(cm^2\text{-sec-ster})^{-1}$ above 10 MeV (or equivalent riometer absorption) we have assembled a list of 217 solar proton events which have been recorded at the earth during the last three solar cycles. We have utilized this list to search for any recognizable pattern between the occurrence of solar proton events and the solar cycle.

Non-relativistic Solar Proton Events. To assemble a list which includes both the ground-level events and the non-relativistic solar proton events that have occurred during the past three solar cycles it was necessary to compensate for the evolution in the various detection techniques. Indirect detection of solar proton events did not stabilize until approximately 1958, and spacecraft measurements were not really systematic until about 1965. Based on contemporary knowledge it is possible to interpret the riometer sensed data to form a useful continuous data base extending from the present back until about 1955. The list of 217 events that we have compiled (Shea and Smart, 1989) was derived from the following sources:

Solar Cycle 19: Primarily riometer or riometer equivalent data supplemented with limited spacecraft data in the early 1960's. All known ground-level events were also included.

Solar Cycle 20: Data from earth-orbiting satellite measurements of solar particle events plus simultaneous polar riometer measurements.

Solar Cycle 21: Primarily from very sensitive spacecraft instruments. The list also includes peak particle flux and fluence whenever these data were available.

Ground-Level Events. The most homogeneous list of solar proton events derived from a standard observational technique is the list of "ground-level events" detected with neutron monitors. The sensitivity of this instrument has been essentially unchanged since its inception in 1953. Although some small events may not have been identified during the 19th solar cycle because of a sparsity of detectors, a more dense net of instruments, installed in the polar regions for the IQSY, has enabled the identification of events with increases of only a few percent since 1966. Figure 1 shows the temporal distribution of these relativistic solar proton events over the past three solar cycles, and the location of the flare associated with each event. Notice that seven of the 35 events have been associated with flares behind the west limb of the sun, whereas only four of these events have been associated with flares east of central meridian. These 35 ground-level events indicate that at least 15% of the significant solar proton events (those with a flux of 10 protons $(cm^2\text{-sec-ster})^{-1}$ at energies > 10 MeV) detected at the earth contained protons with energies > 450 MeV .

Solar Proton Events for Sunspot Cycles 19-21. Since most major flares and proton events occur in conjunction with sunspot activity, we used the monthly mean sunspot number as our major ordering parameter (McKinnon, 1987); however, we used the smoothed sunspot number to define the length of each cycle since the monthly mean numbers have a wide variance.

The top portion of Figure 2 shows the number of solar proton events that occurred each 12-month period after sunspot minimum for the past three solar cycles; the 12-month mean sunspot number for the same 12-month periods is shown in the bottom of the figure. A summary of the number of events for each solar cycle is given in Table 1. The three histograms in the top part of Figure 2 are all different, and beyond the obvious fact that there are more solar proton events during solar activity maximum than at solar minimum, there does not appear to be any repeatable solar cycle pattern.

Using solar minimum as our fiducial mark, we summed the number of solar proton events for successive 12-month periods after statistical sunspot minimum for the past three solar cycles. From these results we find that the majority of solar proton events for the past three solar cycles occurred from the second through eighth years after sunspot minimum.

From an examination of the various events we find that significant solar proton events occur in episodes with a large variance in the distribution. There can be relatively long periods between significant events during the sunspot solar maximum (e.g. 1980); conversely, significant solar proton events, including ground-level events, have occurred during solar minimum (e.g. 1976).

In compiling the list of significant solar proton events we tried to identify each event with a solar flare on the sun, in most cases using the identification given in each of the data sources. In many cases, there were multiple flares on the sun, all of which may have released particles associated with the aggregate particle event observed at the earth. There were two types of sequences of activity, the most common being multiple particle events associated with multiple flares from the same active region such as the events in July 1959, November 1960 and August 1972. The other type of activity sequence occurs when different regions on the sun each independently produce copious solar particles. We have calculated the number of discrete solar proton producing regions associated with proton events detected at the earth for each of the last three solar cycles (i.e. multiple events from the same region contributed to only one episode and was only counted once). The results are included in Table 1. From these calculations we find that for each of the last three solar cycles at least 22% of the significant solar proton events observed at the earth are from solar regions that produce at least two or more discrete proton events.

Table 1 also presents the solar cycle summed fluences at energies greater than 10 and 30 MeV for the past three solar cycles. These can be interpreted as showing a systematic downward trend; however, this trend is not reflected in the maximum sunspot number for the respective cycles. Furthermore, one additional very large solar particle episode at the earth during solar cycle 21 might have contributed enough flux to equalize the fluences for the 20th and 21st cycles.

Table 1. Solar Proton Events for Solar Cycles 19,20, and 21

Cycle	Start*	End	Months in Cycle	No. of Proton Events	No. of Discrete Regions	Solar Cycle summed Proton Fluence > 10 MeV	> 30 MeV
19	May 1954	Oct 1964	126	65	47	7.2×10^{10}	1.8×10^{10}
20	Nov 1964	Jun 1976	140	72	56	2.2×10^{10}	6.9×10^{9}
21	Jul 1976	Sep 1986	123	80	57	1.8×10^{10}	6.1×10^{9}

Solar Cycle 22. The sunspot number for solar cycle 22 is presently increasing with a pattern similar to the rise of cycle 19. The last ground-level event of solar cycle 21 occurred in February 1984. It is now more than five years since we have had a ground-level event detected at the earth, making this the longest period (since 1956) without a ground-level event.

Summary.

1. No recognizable pattern could be found between the occurrence of solar proton events and the solar cycle as defined by the sunspot number.
2. At least 15% of the solar proton events were ground-level events containing protons with energy greater than 450 MeV that were detected by ground-based neutron monitors.
3. At least 22% of the significant solar proton events observed at the earth are from solar regions that produce at least two or more discrete proton events.
4. Although the data base is somewhat limited, particularly during the 19th solar cycle when satellite measurements were extremely limited, the large flux and fluence events of the 19th solar cycle were not totally repeated in the 20th or 21st solar cycles.

References

McKinnon, J. A.: 1987, Sunspot Numbers: 1610-1986 Based on the Sunspot Activity in the Years 1610-1960", UAG-95, NOAA, Nat. Geophys. Data. Cntr., Boulder, Colorado.

Shea. M.A., and Smart, D.F.: 1989, Submitted to Solar Physics.

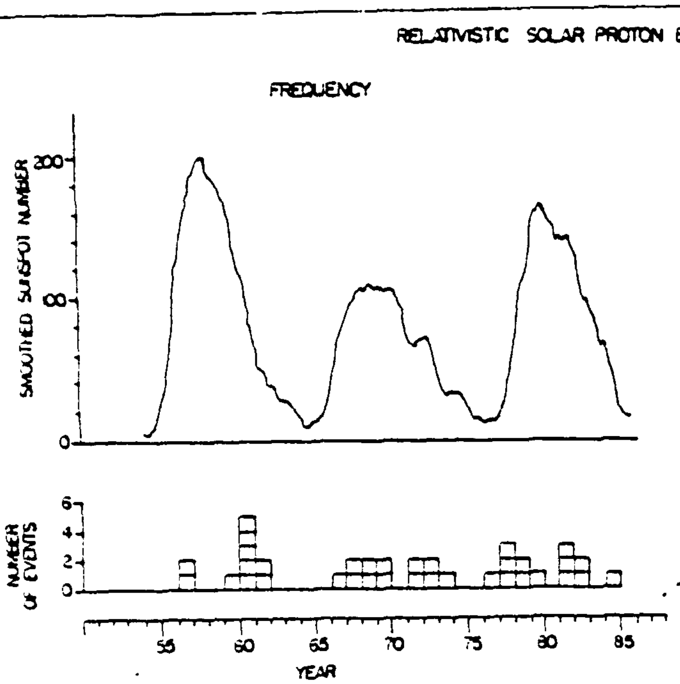

Figure 1. The observed high energy solar proton events (E > 450 MeV) over three solar cycles. Top: smoothed sunspot number. Bottom: number of GLE events each year. Right: location of the source solar flare on the sun.

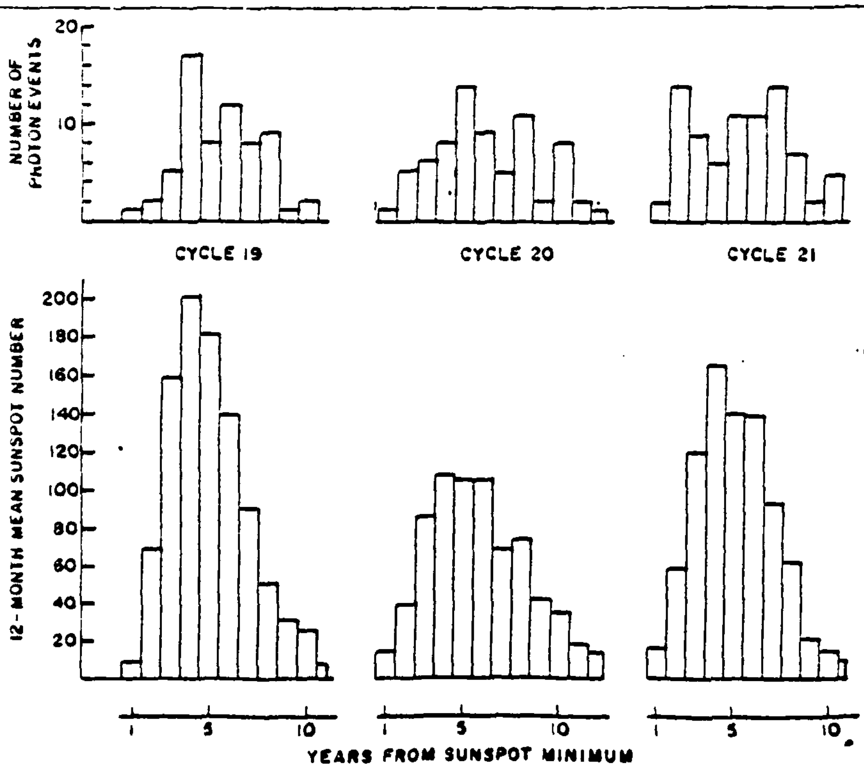

Figure 2. Top: number of significant solar proton events each 12-month period after solar minimum. Bottom: the 12-month mean sunspot number.