SOLAR ENERGETIC PARTICLE EVENTS : PHENOMENOLOGY AND PREDICTION

S. B. Gabriel and G. J. Patrick

Department of Aeronautics and Astronautics, University of Southampton, Highfield, Southampton, England SO17 1BJ.
Email: sbg2@soton.ac.uk, G.J.Patrick@soton.ac.uk

1. ABSTRACT

Solar energetic particle events can cause major disruptions to the operation of spacecraft in earth orbit and outside the earth's magnetosphere and also have to be considered for EVA and other manned activities.

The occurrence of these events is more or less random or at least has been assumed to be so, but there would appear to be some solar cycle dependency with the trend being a higher occurrence rate, or more accurately a higher fluence due to particle events, during a 7 year period, 2 years before and 4 years after the year of solar maximum. During this period, particle events are assumed to have a higher chance of occurring, and are known to be capable of having very large fluences, but the actual time of occurrence is still assumed to be random.

Little has been done to try and predict these events in real-time with nearly all of the work concentrating on statistical modelling. Currently our understanding of the causes of these events is not good. But what are the prospects for prediction? Can artificial intelligence techniques or modern signal processing methods be used to predict them in the absence of a more complete understanding of the physics involved?

2. INTRODUCTION

The effects of solar energetic particle events (SEPEs) on the design and operation of spacecraft are well known and documented. However, on the contrary, our understanding of what causes them is still quite poor. It is more or less generally accepted, although not by all of the scientific community, that coronal mass ejections (CMEs) play a key role in the acceleration of the particles during SEPEs. So if we could predict the onset of CMEs then in principle we could predict the occurrence of SEPEs. In practice, the situation is not that simple because not all CMEs produce large SEPEs at the earth. But this is not the subject of this paper and the reader is referred to other papers for more comprehensive and detailed discussions of the connection between CMEs and SEPEs (1-3). Given that our current understanding of the physical mechanisms that cause SEPEs makes their (deterministic) prediction difficult, if not impossible, is there anything else we can do?

Recently, at the University of Southampton, we have been working on trying to predict SEPEs using artificial intelligence (AI) techniques. So far we have focused on long lead times of the order of 48 hours and neural networks with the ratio of the XL and XS, x-ray fluxes as the inputs and 0 or 100 as the outputs, corresponding to a 'quiet period' or an event, respectively. The overall success rate has been about 65%. After trying many different input combinations to optimise the results, we have concluded that this is probably about the best that we can do with this technique using x-ray fluxes as inputs to the networks. Consequently we have started to look at other potential methods. Firstly, we are looking at alternatives to the x-ray fluxes as inputs and secondly can we perhaps use some of the more modern signal processing techniques, such as wavelets. Other inputs that have been used include solar radio data from various ground observations and the results of these investigations have been presented elsewhere (4).

Work has begun on the possibilities of using wavelet techniques (non-decimated wavelet transforms) for time-series prediction but this work is at a very early stage and there are no results as yet. The possibility of looking at differences in the spectral characteristics before event and non-event periods has begun and other 'proxy' data sets have been gathered but again no results are available yet. The paper will then describe the data sets that have been assembled and present some preliminary results on the phenomenology and statistics of the 10 MeV fluxes prior to events and quiet periods.

3. THE DATA

A set of data on proton fluxes, x-ray fluxes, plage indices, radio fluxes and sunspots has been developed at different time resolutions. For a time span, centred on the event (or quiet period) and extending 81 days (approximately 3 solar rotations) before and afterwards, daily averages were calculated, while for periods of 5 days before and 2 after and 7 days before and 12hrs after, hourly averages were derived.

The list of SEPEs was taken from the JPL-91 model which uses IMP data and is based on a criterion of a threshold of a daily averaged flux at E> 10 MeV of 1 p.f.u.. This list spans the period 1965 to 1989. Each event has been assigned a category depending on its size and nature. This is a purely qualitative measure of the event but may be helpful in filtering the list. There are 5 classes of events:

1 = Well Defined.
The >10MeV proton flux is clearly above the background level and there is a clear commencement.

2 = Long Rise.
The >10MeV proton flux rises slowly over a long period of time (up to 24 hours) before reaching a maximum. This makes the start time of the event difficult to pinpoint.

3 = Poorly Defined.
A proton event is visible but the >10MeV flux is not significantly above background. The event may also have a short duration (<1 day).

4 = Continuation.
The proton event is a continuation of an ongoing proton event and occurs at a time when the background proton flux is already elevated. The source of the event may be a separate solar flare, or could be an enhancement of pre-existing protons by an IP shock.

5 = Unusable.
Indicates that there is missing data at the time of the event, that no event could be found at the stated time, or that the event was so small its existence was questionable.

Quiet Periods have been defined as times at which the >10MeV Proton flux has been at background level for a period of at least 10 consecutive days. 340 quiet periods have been taken at random from solar active years between 1977 and 1999 inclusive. Solar active years are defined by Feynman et al. as the 2 years before and the 4 years after the year of solar maximum, and are given below in Table 1 (5).

Solar Maximum	Period of Active Years
1968.9	1966.9-1973.9
1979.9	1977.9-1984.9
1989.9	1987.9-1994.9
2000.2	1998.2-

Table 1 Definition of solar cycle active years.

4. PRELIMINARY RESULTS ON 10MeV PROTON FLUX STATISTICS

4.1 Analysis Method

Class 1 events only were studied to see if there were any differences in the proton fluxes prior to an event and prior to a non-event period. In the process of doing this the question arose as to whether or not there were any differences in the average fluxes with the size of the event in terms of its fluence.

Average fluxes from –168 hours to –48 hours before the start of an event were calculated. Missing or corrupted data was set equal to zero.

4.2 Results

Figure 1 shows a typical example of the fluxes before a large event, in this the largest amongst the Class 1 list. One of the problems associated with trying to look at these events can be clearly seen in this figure and that is the data outages. Since the flux is plotted on a log scale these missing data points are not shown at all (even though they have been set as zero).

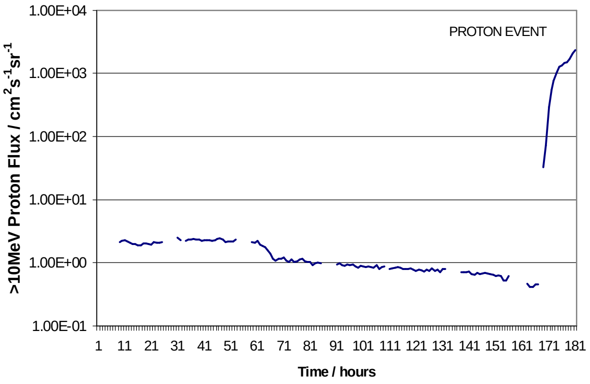

Figure 1 Behavior of >10MeV proton flux prior to the largest class-1 event.

There are few if any features which might be interpreted as pre-cursors, except perhaps for the small enhancement between about 10 and 60 hours and the apparent dip below the 1.0 level following this enhancement.

Figure 2 shows a similar plot for a typical quiet period randomly selected from the list but for a period 120 hours before to 48 hours after the selected quiet period. There is not, as one would hope from a prediction point of view, a clear feature and the average value of the flux looks significantly lower than that for the very large event. But this is for one event and one quiet period.

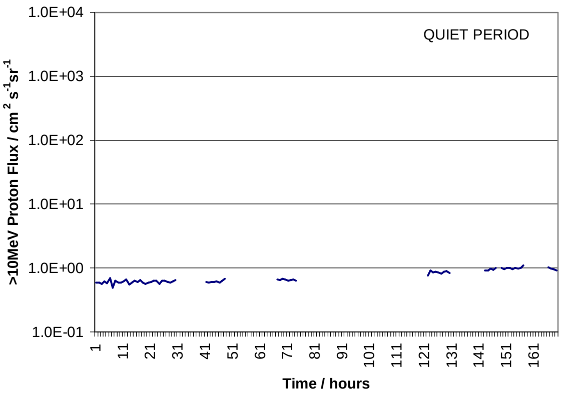

Figure 2 Behaviour of proton flux prior to a quiet period (randomly selected).

Figure 3 shows the average value of the flux from –168 to –48 hours plotted against the log to base 10 of the fluence of the event for all of the class1 events. There is a great deal of scatter, although one could perhaps convince oneself that there was a trend towards larger average fluxes with increasing fluences. The average of these average fluxes is 0.3 and the average of the averages of the quiet periods is 0.65. This is perhaps contrary to what one would have expected. But, the selection of the quiet periods at random during solar maximum may not be ideal and each of the quiet periods needs to be checked again manually since some spot checks have revealed that there may be small events or enhancements during the periods before the quiet periods.

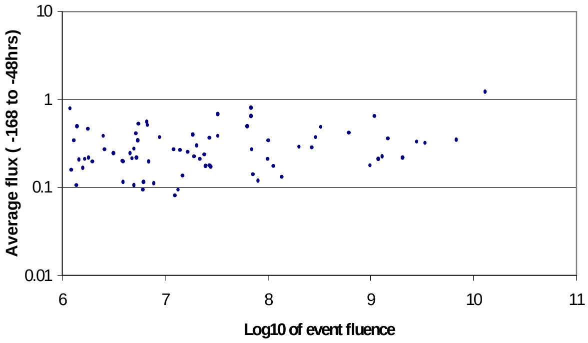

Figure 3 Average >10MeV proton flux during the period prior to an event (-168 to –48 hours) plotted against the >10MeV fluence of the event.

Figure 4 plots the average >10MeV proton flux for the case of events and quiet periods for the period prior to occurrence. The average proton flux at around 15 hours is slightly higher than that associated with quiet periods although further analysis is required to quantify any predictive capability of this feature. Experience has shown that differences between quiet period and event population distributions are not always representative of individual examples.

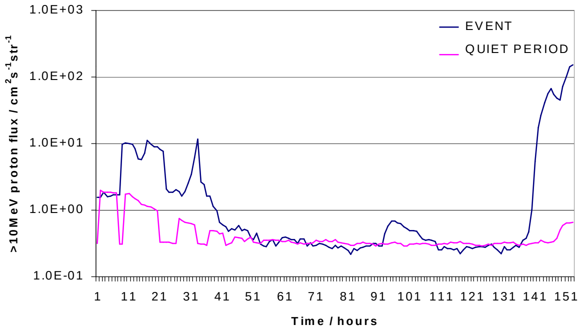

Figure 4 Comparison of average >10MeV proton flux for events and quiet periods.

5. CONCLUSIONS

A search for pre-cursors to SEPEs using a range of solar parameters has been initiated. Very preliminary results looking at statistical variations in the average proton fluxes before events and quiet periods does not look promising. However, further refinement in the selection of the quiet periods and also the events is required. Work will continue with similar analyses of the other solar parameters and with the application of wavelet techniques.

6. REFERENCES

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