PERIODICITIES IN THE OCCURRENCE RATE OF SOLAR PROTON EVENTS

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Abstract. Power spectral analyses of the time series of solar proton events during the past three solar cycles reveal a periodicity around 154 days. This feature is prominent in all of the cycles combined, cycles 19 and 21 individually but is only weak in cycle 20. These results are consistent with the presence of similar periodicities between 152 and 155 days in the occurrence rate of major solar flares, the sunspot blocking function ($P_e$), the 10.7 cm radio flux ($F_{10.7}$) and the sunspot number ($R_z$). This suggests that the circa 154-days periodicity may be a fundamental characteristic of the Sun. Periods around 50-52 days are also found in the combined data set and in the three individual cycles in general agreement with the detection of this periodicity in major flares in cycle 19 and in $P_e$, $F_{10.7}$, and $R_z$ in cycle 21. The cause of the 155 day period remains unknown. The spectra contain lines (or show power at frequencies) consistent with a model in which the periodicity is caused by differential rotation of active zones and a model in which it is related to beat frequencies between solar oscillations, as proposed by Wolff.

1. Introduction

A periodicity of about 152 days exists in the occurrence rate of solar flares as first discovered using X-ray emission by Rieger et al. (1984) and subsequently confirmed in microwave flares (Bogart and Bai, 1985) and Hα flares (Ichimoto et al., 1985). More recently, Lean and Brueckner (1989) have searched for periodic behavior in the range 100–500 days in the sunspot blocking function, the 10.7 cm radio flux, the sunspot number and the plage index and found a periodicity at around 155 days in all of these parameters except the plage index. The cause of the periodicity at about 152–155 days remains unknown.

Here we present an analysis of the occurrence rate of solar proton events with time-integrated flux values greater than $10^6$ protons cm$^{-2}$ at energies greater than 30 MeV. We have analyzed data from the last 3 solar cycles 19, 20, and 21 and find a periodicity at around 152 days in all 3 cycles individually and also in the combined time series of the 3 cycles. This finding is considered to be significant in that it adds a further confirmation to the 150-day periodicity and that it may clarify our understanding of the underlying mechanisms responsible for the production of solar energetic particle events, since if the cause of the 150-day period in both flares and proton events is the same, then an explanation of this periodicity would be applicable to proton events.

The data set used, was that compiled by Armstrong, Brungardt, and Meyer (1983) and Feynman et al. (1988, 1990a). The list, published in Feynman et al. (1990b) included a total of 200 proton events that occurred between 1956 and 1985 (solar cycles 19, 20, and 21). We constructed a time-series signal consisting of unit pulses (zero-width)
occurring on the day on which each event started. This sequence was then zero-meaned and a frequency analysis performed using both a Fast Fourier Transform (FFT) technique and Maximum Entropy (MEM) technique. In this paper, we focus the discussion on those periods relevant to the problem of the existence and causes of the 152-day period. We also briefly present observations of a circa 50-day period for comparison with other work.

2. The Periodicity at around 154 Days

The MEM result, for the combined data set, 1956–1985, is shown in Figure 1. The highest peak is at a frequency of $0.9 \times 10^{-8}$ Hz corresponding to a period of 4000 days or 10.95 years and can be identified as the familiar 11-year solar cycle. The next highest peak (in the range shown) is at a frequency of $7.5 \times 10^{-8}$ Hz corresponding to a 153.8-day periodicity. This is, within the error of the determinations, very close to other reported values for a periodicity around 152 days: 154 days by Rieger et al. (1984) using the Gamma-Ray Spectrometer (GRS) aboard SMM, 152 days for flares with GOES class above M2.5 (Rieger et al., 1984), 151.8 ± 1 days for microwave flares for solar

Fig. 1. Maximum entropy spectrum of solar proton events, combined data set, 1956 (February 23)–1985 (July 4). The periods of the identified peaks are in days unless stated otherwise.