Statistical study of short quiescent times between flares

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Abstract. The study of the statistical distribution of short quiescent times (≤ 30 minutes) between solar flares has been investigated on a 1D MHD model. A power law behaviour is found which indicates the existence of sympathetic flaring. This prediction is supported by recent observations.

Solar flares are the most violent phenomena observed in the solar system. It is believed that they play a fundamental role in maintaining a "hot" corona. Statistical analyses of observational data (Dennis, 1985; Crosby et al., 1993; Pearce et al., 1993), in terms of probability distribution functions (pdfs), revealed the scale-invariance property of solar flares: the pdfs \(N(x)\) of different quantities \(x\), such as the peak luminosity (P), the total energy (E) or the duration (D) of flare events, follow widely extended power laws, viz. \(N(x) \sim x^{-\alpha} \) (\(x = P, E, \text{ or } D\)) with the indices \(\alpha_P \approx 1.7\), \(\alpha_E \approx 1.5\) and \(\alpha_D \approx 2.2\). This apparent absence of a characteristic length scale allowed us to see solar flares in a new way, like a Self-Organised Critical (SOC) system (Lu and Hamilton, 1991; Vlahos et al., 1995). Although SOC models do not make a direct connection with physical ingredients, like the magnetic field in the case of flares, with simple rules they are able to reproduce well the statistical properties observed. The limitation of SOC models in the predictability of flares statistics was however recently discussed by Boffetta et al. (1999). The authors have studied the pdf of long quiescent times (also called waiting times), \(\tau\) (for \(\tau \geq 6\) hours), defined as the time intervals between two successive bursts. This observational analysis, based on 20 years of data obtained from the GOES sensors shows clearly a power law behaviour with an index \(\alpha_\tau \approx 2.4\). This kind of behaviour is an indication of the existence of sympathetic flaring (i.e. the triggering of one flare by another) on long time-scales. It corroborates what we already knew for short quiescent times (Pearce et al., 1993; Wheatland et al., 1998). Then Boffetta et al. (1999) concluded that this result was in contradiction with SOC models of solar flares, where the system is driven at a constant rate (Lu and Hamilton, 1991), and thus for which events occur randomly in time as a Poisson process. Note that there are many SOC models in the literature like nonconservative models (Christensen and Olami, 1992) which are able to produce power laws for the distribution of quiescent times. Therefore the distinction discussed above between SOC and turbulence is not so obvious (although it is for many other aspects!).
Do we really have observed a signature of sympathetic flaring at any time-scale? According to Wheatland (2000) the answer is no. Indeed in his paper it is shown that the apparent power law behaviour observed for long quiescent times is simply the consequence of the wide variation in the flaring rate during several solar cycles. However for short quiescent times we do have sympathetic flaring. The overabundance of short quiescent times (10 s to 10 minutes) constructed by Wheatland et al. (1998) from bursts observed in hard X-ray may be interpreted as a time correlation between secondary events (bursts) generated by a major event (flare). Then solar flares, defined as events having several episodes of hard X-ray emission, would be independent events.

A first investigation of the quiescent times statistics in the context of magnetohydrodynamics (MHD) is described by Boffetta et al. (1999) through a shell model. The idea of a shell model is to reproduce the non-linear dynamics by including only a set of nearest-neighbour non-linear interactions while preserving the quadratic invariants, but otherwise ignoring the details of the spatial structures. In spite of its simplicity, this model appears to be rich enough to reproduce the observed statistics for P, D and E (see above). However, and in apparent contradiction with the observations, a power law behaviour is also observed for the pdf of the long quiescent times.

The aim of this paper is to investigate the statistical distribution of short quiescent times ($\leq 30$ minutes) on a 1D MHD model of coronal loops (Galtier and Pouquet, 1998). Several turbulent MHD models of coronal loops have been recently developed but few statistical studies of dissipative events have been reported in the literature mainly because of the difficulty, from a numerical point of view, to produce statistical data of good quality (Einaudi et al., 1996; Dmitruk et al., 1998; Georgoulis et al., 1998). For that reason, a reduction to a 1D MHD model has been proposed where the magnetic loop at the origin of the flare is reduced to a magnetic line. Then the events generated are shocks whose dissipation is a source of heating for the corona. It was shown that this model was able to reproduce solar flares properties like the histogram of peak luminosity (Galtier and Pouquet, 1998; Galtier, 1999). The details and the results of the numerical computation considered here, with a spatial resolution of 4,096 grid points, are given in Galtier (1999). The main signal analysed in the present study is the Joule dissipation ($\sim \langle J^2(x) \rangle$, where $J$ is the current density) averaged over the length of the loop for a simulation of 42 hours of solar activity. Each dissipative event of the signal defines a flare and the quiescent times are then taken to be the time intervals between two successive events, i.e. two successive maxima, following the criterion also used in Wheatland et al. (1998) and in Boffetta et al. (1999). The computation of the histogram of
Figure 1. Histogram $N(\tau)$ of the short quiescent times (in second) between two successive dissipative events. The straight line corresponds to a slope of $-2.3$.

The physical picture for long and short quiescent times appears to be very different. For long quiescent times (longer than the lifetime of a flare) no time correlation seems to be observed, however for short quiescent times (of the order or smaller than the lifetime of a flare) we do observe a time correlation. As it is proposed by Wheatland et al. (1998) the origin of sympathetic flaring in the MHD model is possibly due to the correlation between secondary events (bursts) generated by a major event (flare). In fact typical dissipative events last several
minutes (Galtier, 1999) and are often composed in a main flare followed by secondary events. The detailed analysis, including spatial information along the coronal loop, on typical examples of dissipative events reveals a non-trivial correlation between bursts (Galtier, 2000) for short time-scales. This spatial information available in the MHD model appears to be an important ingredient to understand the origin of sympathetic flaring.

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