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# ANALYSIS OF TIME REGIMES IN FIRE SEQUENCES OCCURRED IN PATAGONIA, ARGENTINA

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Time regimes in fire data recorded from 1992 to 2007 in a fire vulnerable area of Patagonia (Argentina) were revealed by using the Allan Factor statistics. The obtained results show the presence of seasonal periodicities, superimposed to three time-scaling regimes, which characterize the point process of the fire sequence as a fractal time process with a rather high degree of time-clusterization of the events.

*Keywords*: Fires; Patagonia; Allan Factor; scaling.

## 1. Introduction

A sequence of fires is a stochastic process, whose events are featured by spatial location and occurrence time and marked by the size of burned area. Dynamics of fire processes are well described using the idea of self-organized criticality (SOC) [1]. SOC has been developed to explain complex dynamical behaviours in many natural phenomena represented as extended dynamical systems operating at states of critical equilibrium with no spatial or temporal scales other than those deduced from the size of the system [2]. The main features of SOC systems are spatial fractality, "$1/f\alpha$-noise" and power-law frequency-size distribution. Most of the existing literature regarding forest-fires focused on the problem of the frequency-burned area distribution, feeding a fruitful debate about the presence and the justification of power-law relationships and providing more or less complex models to fit with real observations [3]. All these studies deal with one of the parameters that define a fire event, i.e. its intensity given by size of burned area. But the

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concept of self-organized criticality also implies that the time evolution of the system is time-scaling.

## 2. Study Area

The analysis performed in the present study aims at investigating the temporal properties in the fire sequence recorded in a fire vulnerable area in Patagonia (Argentina) from 1992 to 2007. Fig. 1 shows the monitored area. The study area includes the Nahuel Huapi National Park (NHNP), monitored by Coordination of Figth against Forest Fires of National Parks (CLIF), and the region at east included in the Rio Negro province, monitored by Service of Prevention and Figth against Forest Fires (SPLIF). This area includes San Carlos de Bariloche city. The NHNP extends up to 758,000ha and is located in NW Patagonia (Argnetina). The SPLIF jurisdiction covers an area of approximately 120,000ha. It extends from the border with Chile and NHNP, at the west, up to the 500mm annual mean precipitation Isohyet, at the east, and from parallel 42°, at the south up to the border with the Neuquén and Rio Negro provinces, at north [19]. In the study area, a strong rainfall gradient exists, with mean annual precipitation falling from 4000 mm in the West (41º01 ' S, 79º49 ' W) to 250 mm in the East (41º10 ' S, 70 º 41 ' W), in 120 km [21]. Precipitations are concentrated in the autumn–winter period, and a moderate hydric stress can be detected towards the east during the summer. Across this gradient the vegetation changes dramatically, being dominant in the West the Nothofagus spp. and Austrocedrus chilensis forests and in the East the xeric steppe with shrubs (Fabiana imbricata and Mulinum spinosum) and tussock grasses (Stipa speciosa) [20]. During dry winters or summers large burned areas in forest environments are expected, and a summer with low precipitation is enough for this to happen in the steppe. This meteorological situation increases the risk of severe and extensive fires.

## 3. Method

The well known method to investigate the temporal properties of a time series is the power spectral density (PSD) S(f), obtained by means of a Fourier Transform (FT) of the series. The PSD gives information on how the power of the series is concentrated at various frequency bands [4]. This information allows identifying periodic, multi-periodic or non-periodic frequency patterns. Usually the logarithmic power spectrum plot, that is the power spectrum plotted in log-log scales, is used to analyze broadband behaviour. The power-law dependence (linear on a log-log plot) of the PSD, given by $S(f) \sim f^{\alpha}$, is a hallmark of the presence of time-scaling in the data. The properties of the series can be further classified in terms of the numerical value of the spectral exponent: $\alpha = 0$ features white noise time series, characterized by absence of time correlations; while $\alpha \neq 0$ is typical of pink noise time series, characterized by the presence of time correlations.
A fire sequence is a temporal point process, given by a set of events occurring at random locations in time [5], and the simple application of the FT is not possible. The fire data can be represented by a finite sum of Dirac's delta functions centered on the occurrence times $t_i$, with amplitude $A_i$ proportional to the burned area:

$$y(t) = \sum_{i=1}^{N} A_i \delta(t - t_i) , \tag{1}$$

where N represents the number of events recorded.

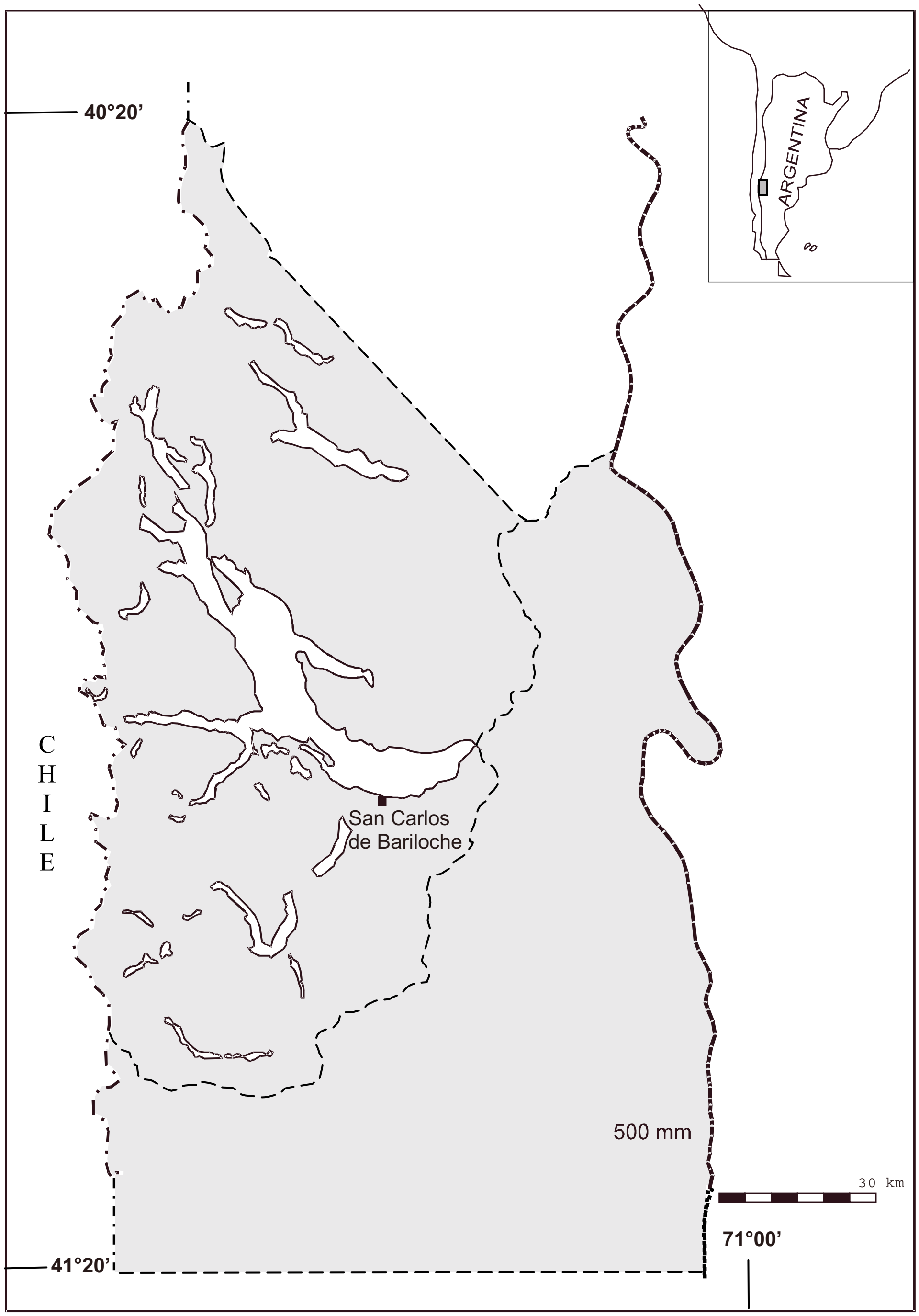


Fig. 1. Study area.

Then dividing the time axis into equally spaced contiguous counting windows of duration $\tau$, which is called timescale, a sequence of counts $\{N_k(\tau)\}$ is produced , with $N_k(\tau)$ denoting the number of fire events in the k-th window [6]:

$$N_k(\tau) = \int_{t_{k-1}}^{t_k} \sum_{j=1}^{n} \delta(t - t_j)dt \,. \tag{2}$$

The following quantity, the Allan Factor (AF), can be defined as

$$AF(\tau) = \frac{<(N_{k+1}(\tau) - N_k(\tau))^2>}{2<N_k(\tau)>}, \tag{3}$$

which is related to the variability of successive counts [7,8]. The AF has been largely used to investigate the time dynamics of earthquakes [9].
If the point process is time-correlated, then the AF varies with the timescale $\tau$ with a power-law form:

$$AF(\tau) = 1 + \left(\frac{\tau}{\tau_1}\right)^{\alpha} \tag{4}$$

over a certain range of timescales $\tau$; and the exponent $\alpha$ quantifies the strength of time-correlation; $\tau_1$ is the fractal onset time and marks the lower limit for significant scaling behaviour in the AF, so that for $\tau \ll \tau_1$ the time-scaling property becomes negligible at these time scales [10]. AF assumes values near unity for Poisson processes [11]. Therefore, if $\alpha=0$ the point process is Poissonian, which means that the series is memoryless and constituted by independent events; while if $\alpha>0$ the process is characterized by time-scaling behaviour, which means that the series is time-correlated.

## 4. Data Analysis and Discussion of the Results

During the observation period a sequence of 9770 fires has been recorded. The present study aims to recognize time regimes in analysed fire sequence.

Figure 2 shows the relation $AF(\tau)\sim\tau$ in log-log scales for the whole sequence. Equation (3) has been calculated for timescales $\tau$ ranging between 1 day and T/10, where T is the total observation period in days. The analysis of the AF curve allows getting insight into several features characterizing the analysed fire sequence:

i) The fire activity of the investigated area in Patagonia is not Poissonian, because the AF curve is not flat for all the timescales $\tau$. This result indicates the presence of time-clustering behaviour in the fire dynamics, which implies the presence of time-correlation structures in the time distribution of the fire events.

ii) Three time-scaling regimes (given by the linear parts of the log-log AF curve in Fig. 2) are clearly visible: the first ranging between ~1 day and ~6 days, with scaling exponent $\alpha \sim 0.5$; the second ranging between ~6 days and ~1 month, with scaling exponent $\alpha\sim1.1$; the third ranging between ~1 month and ~4 months, with scaling exponent

$\alpha \sim 1.7$. The presence of scaling regimes in the AF statistics evidences the self-organization of the fire activity: fires have a direct impact on vegetation, which, in turn, contributes to the future fire activity [14]; therefore, the existence of feedback mechanisms involving both fires and the ecological patterns (vegetation type, age, physiognomy, etc.) gives rise to correlation structures and memory phenomena [15, 16], revealed by the time-scaling behaviour in the AF statistics. The vegetation patterns constrain and at the same time are constrained by the processes that generate them [17]. A fire occurring in an area, that was never burned before, creates a pattern of burned and unburned vegetation patches, which will influence the occurrence of the next fire within a continuous feedback dynamics [17, 18]. The presence of different scaling regimes indicates that different dynamical mechanisms govern the same sequence over the three timescale ranges, and the different values of the scaling exponent $\alpha$ suggest different strengths of the power-law fluctuations of the fire sequence. The different mechanisms could be due to mixed natural and anthropogenic causes. The crossover timescales of 6 days and 1 month could have probably an anthropogenic nature. The crossover at about 4 months could be connected with the mean duration of the fire season (occurring in the austral summer).

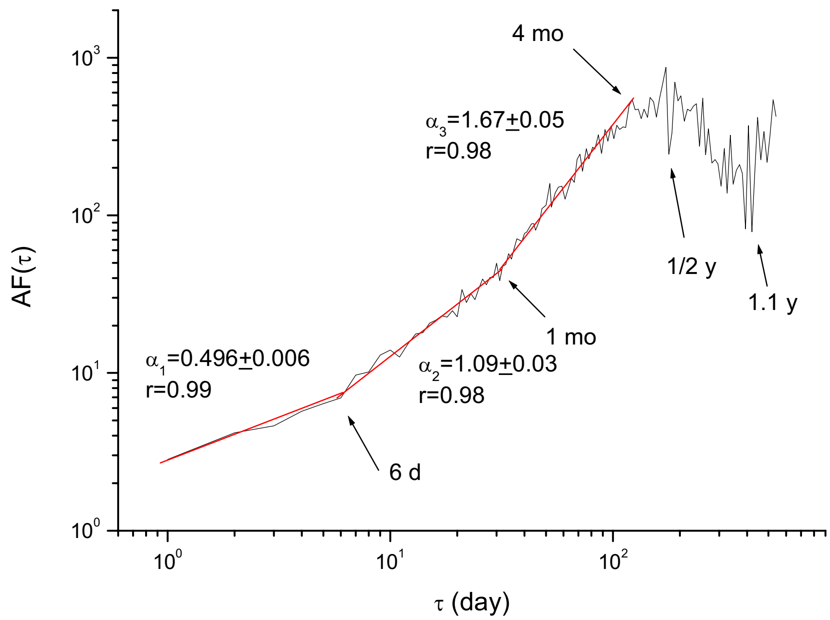


Fig. 2. AF curve for the fire sequence.

iii) The time dynamics of the fire sequence is characterized by the presence of periodicities, shown by the drops in the AF curve (indicated by arrows in Fig. 2). The periodic component at about ½ year is clearly connected with the typical seasonal variability, due to cumulative effects of weather, climate as well as normal bio-physiological life cycles; the vegetation, in particular grass, has a seasonal growth cycle, and, as expected, the state of grassland has an important influence on the ignition and spreading of fires. The periodic component at about 1.1 years can be related with the yearly cycle of vegetation, connected with the meteorological and climatic yearly cycle.

## 5. Conclusions

The applied AF methodology has revealed the presence of several time regimes (periodicities and scaling regimes) in the fire sequence of a fire-vulnerable area in Patagonia (Argentina), connected with the meteorological and climatic conditions of the area. Such kind of processes describe well the systems governed by positive feedback mechanisms.

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