

## EXAMINATION OF THE CORRELATIONS BETWEEN FOREST FIRES AND SOLAR ACTIVITY USING HURST INDEX

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**Abstract:** The aim of this paper is to find the functional dependence between the occurrence of forest fires and the factors inherent to solar activity. It has been shown that the amplitude of number of forest fires in the USA for warm period 2004-2007 is not time dependent. The method of seasonality indices for seasonal components filter was used for the decomposition of time series. In order to test this hypothesis the correlation analysis was held between the factors  $X_i$  and the number of fires taking into account time delay (lag) between the onset of fires and solar activity. The results of this analysis show that any correlation coefficient is not higher than 0.2. For determination of the degree of randomness for time series of input and output parameters, the R/S analysis was conducted. The Hurst index was used for determining the depth of their memory. Based on the proximity of the Hurst index for the 10.7 cm solar flux categories and small forest fires, a reasonable assumption can be made that the dynamics of these time series is heavily dependent on the same factors.

**Key words:** forest fires, solar activity, Hurst index, USA

### Introduction

The previous research, based on numerous examples, gave evidences on the causative-effective link between the processes on the Sun and the occurrence of forest fires of undetermined cause (Todorovic, Radovanovic & Stevančević, 2007; Radovanović, Ducić & Lukovic, 2007; Ducić, Milenkovic & Radovanovic, 2008; Radovanović & Gomes, 2009; Radovanović, 2012). However, in the absence of extensive data base, these attempts were based on tracking the timeline of events. It was established that a sudden influx of charged particles compulsorily preceded the occurrence of fires. The hypothesis given by previously mentioned authors has been based on the assumption that the protons and electrons in certain conditions are capable to penetrate the Earth's

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atmosphere, reach the surface and in the contact with biomass cause the initial phase of fire. The satellite measuring of the flow of protons and electrons focuses the attention of researchers on the effects of their sudden influx. Namely, in such situations the question is when and where fires can be expected, that is, whether the absorption of particles will occur in the concrete case by increased air humidity and/or clouds or there are indications that they will be able to penetrate the ground (Radovanovic, Stevančević & Štrbac, 2003; Radovanoivć, Lukić & Todorović, 2005, Radovanović, Milovanović & Gomes, 2009; Radovanović, 2010). Gomes et al. (2009) gave the theoretical model in which it has been explained how it comes to the propagation of particles towards the topographic surface.

In this paper it was tried to determine the possible existence of correlations on the basis of daily values for the period 2004-2007 in the example of the USA. The decision to test the hypothesis especially in the case of this country was made due to the availability of data on fires in a relatively large area and on a daily basis. Colder parts of the year in the studied period were not taken into consideration, because of the rare occurrence of fires in that period.

### **Data and methods**

The number of large fires ( $F_{large}$ ) and small fires ( $F_{small}$ ) are taken to be the output variables for this research. The input parameters (as the indicators of the solar activity) were selected as follows: the flow of  $>1$  MeV protons (X1), the flow of  $>10$  MeV protons (X2), the flow of  $>100$  MeV protons (X3), the flow of  $>0.6$  MeV electrons (X4), the flow of  $>2$  MeV electrons (X5), the 10.7 cm solar flux (X6), the solar wind speed max (X7) and the solar wind speed average (X8). Daily data for the forest fires in the USA for the period from May to October 2004 – 2007 have become the information base for the calculation (Fig.1).

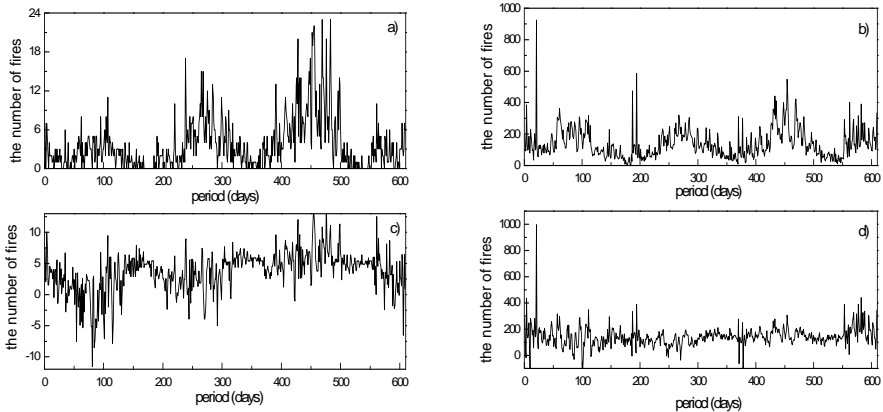


Figure 1 Number of large (a), (c) and small (b), (d) fires. Real data (a), (b), data without seasonal component (c), (d)

Data on the flow of protons, electrons and solar flux are retrieved from: <http://www.swpc.noaa.gov/ftpmenu/warehouse.html>. Data on average solar wind speed are retrieved from: <http://umtof.umd.edu/pm/crn/> and data on maximum solar wind speed are retrieved from <http://www.swpc.noaa.gov/ftpdir/lists/ace/>. Data on forest fires are retrieved from: <http://www.predictiveservices.nifc.gov/intelligence/archive.htm>. According to this source significant fires are those that exceed 300 acres in grass and brush fuels (fuel models 1 through 7), 100 acres in timber fuels (fuel models 8 through 13), or have a Type 1 or 2 team assigned.

The cyclical occurrence of fires for  $F_{small}$  and  $F_{large}$  can be seen in the Fig. 1 (a, b). It is noticeable that the amplitude of number of fires is not time dependent. Therefore decomposition of time series  $F_{small}$  and  $F_{large}$  applying additive model should be used. This model is the following:  $Y_t = T_t + S_t + \epsilon_t$ , where  $Y_t$  - time series,  $T_t$  - trend component,  $S_t$  - seasonal component,  $\epsilon_t$  - "white" noise (occasional component) (Boxall et al., 2009). We used the method of seasonality indices for seasonal components filter. Firstly, time series smoothing using the moving average was calculated. This made it possible to filter out small fluctuations and to identify the basic trend of time series. It is numerically equal to the arithmetic mean value of time series for several periods: in our case it was 184 days, i.e. six months/ May to October 2004-2006. For 2007, the data base is limited to 25 June.

Generally, the simple moving average for point t is defined as follows:

$$SMA_t = \frac{1}{n} \sum_{i=0}^{n-1} y_{t-i}$$

, where n - the number of values of time series,  $y_{t-i}$  - value of time series in point (t - i). Since the obtained values for the moving average are shifted relatively to the real values of time series, they must be averaged once more with the averaging period equal to 2, which means to calculate the centred moving average. Subtracting time series, formed from centred moving averages, which is a general trend of time series, from the original time series, seasonal component evaluation was obtained. In its turn, these evaluations were also averaged for the appropriate days of all the considering years. In the additive model seasonal effects in the period must be similar. Thus the adjustment factor was found for it and the value of seasonal component was corrected according to it. Values of the seasonal component, obtained in such a way, represent the ratio of the number of fires in a given day of the year to the average number of fires per year and thus receive either positive or negative values.

Table 1 The pair correlation coefficients between input ( $X_i$ ) and output ( $F_{large}^L$  ( $small$ )) variables with time lag  $L = \overline{0,5}$

	X1	X2	X3	X4	X5	X6	X7	X8
$F_{large}^0$	-0.02	0.01	0.00	0.04	-0.02	-0.15	0.05	0.05
$F_{large}^1$	-0.04	-0.03	-0.01	0.02	-0.04	-0.16	0.04	0.05
$F_{large}^2$	-0.04	-0.02	-0.02	0.00	-0.02	-0.17	0.02	0.04
$F_{large}^3$	-0.04	-0.03	-0.03	-0.01	-0.02	-0.18	0.02	0.03
$F_{large}^4$	-0.05	-0.03	-0.03	-0.01	-0.02	-0.18	0.02	0.02
$F_{large}^5$	-0.02	-0.02	-0.02	0.01	-0.04	-0.19	0.02	0.02
$F_{small}^0$	-0.02	-0.01	-0.01	0.03	-0.02	0.09	-0.04	0.02
$F_{small}^1$	0.01	0.01	-0.01	0.00	-0.02	0.09	-0.03	0.01
$F_{small}^2$	-0.02	0.02	0.01	0.00	-0.01	0.07	-0.03	-0.04
$F_{small}^3$	-0.04	-0.02	0.03	0.01	0.02	0.07	-0.02	-0.07
$F_{small}^4$	-0.05	-0.04	0.01	0.01	0.04	0.07	-0.07	-0.05
$F_{small}^5$	-0.03	-0.03	-0.02	0.00	0.03	0.05	-0.07	-0.03

Purified from the effects of seasonal fluctuations, time series are shown in the Figure 1 (c, d). Here one can see that sudden outbreaks of fires are observed during the studied period. To test this hypothesis the correlation analysis was held between the factors Xi and the number of fires taking into account time delay (lag) between the onset of fires and solar activity. The results of this analysis are shown in the Table 1. As it can be seen any correlation coefficient is not higher than 0.2.

It means that there are no linear relationships between mentioned factors. Therefore it is necessary to apply methods of nonlinear analysis to test the hypothesis of a functional relationship between the onset of fires and solar activity.

For determination of the degree of randomness for time series of input and output parameters, the R/S – analysis was conducted (Lenskiy & Seol, 2012). It made possible to determine the depth of their memory, using the Hurst index. To do this, the following equation was solved for each of the factors (Peters, 2003):

$$(R/S)^n = c n^H \quad (1)$$

where (R/S) – normalized magnitude, i.e. scope of partial sums of deviations of time series from its average, scaled by the standard deviation, n– length of time series, c– constant, H – the Hurst index.

To solve the equation each of the input Xi,  $i = \overline{1,8}$  and output time series Flarge and Fsmall with length m was transformed into a sequence hn with length (m -

$$h^k = \log\left(\frac{x_i^{k+1}}{x_i^k}\right)$$

1), where . After that, the investigated time series were divided into A contiguous sub periods with length n. Each sub period has been marked as Ia, and each element of the sub period – hk,  $k = \overline{1,n}$ . Then for each sub

period the average meaning  $\overline{h^a} = \frac{1}{n} \cdot \sum_{k=1}^n h^{k,a}$  was determined and the scope of

accumulated sums  $R^a = \max_k \left( \sum_{l=1}^k (h^{l,a} - \overline{h^a}) \right) - \min_k \left( \sum_{l=1}^k (h^{l,a} - \overline{h^a}) \right)$  in terms of each sub period was calculated.

Standard deviation Sa for each sub period was defined as follows:

$$S^a = \sqrt{\frac{1}{n} \cdot \sum_{k=1}^n (h^{k,a} - \overline{h^a})^2} \quad (2)$$

Then each scope of accumulated sums  $R_a$  was normalized by dividing its corresponding standard deviation  $S_a$ . Then the average value  $(R/S)_n$  for length  $n$  was defined as:

$$(R/S)_n = \frac{1}{A} \cdot \sum_{a=1}^A \frac{R^a}{S^a} \quad (3)$$

Increasing the length of sub periods  $n$  and calculating for all of them  $(R/S)_n$ , the Hurst index was determined by solving the simple least-squares linear regression equation using logarithmic transformation:

$$\log((R/S)_n) = \log(c) + H \cdot \log(n) \quad (4)$$

The results of these calculations are shown in the Table 2. The variables  $X_4$  and Flarge were not analyzed because their deviation is smaller than the dispersion.

Table 2 The results of R/S analysis for time series

Variable	Hurst index
$X_1$	0.5826
$X_2$	0.6252
$X_3$	0.4526
$X_5$	0.5948
$X_6$	0.9186
$X_7$	0.7562
$X_8$	0.7246
$F_{small}$	0.9226

As one can see from the previous table the Hurst index of  $X_3$  variables is closer to 0.5 and of  $X_1$  and  $X_5$  to 0.6. It means that these variables describe some stochastic processes. And on the contrary, the Hurst index that is within 0.72-0.76 (for  $X_7$ ,  $X_8$ ) shows the dependence of the dynamics of these factors on their values in previous periods. Proximity of the Hurst index for  $X_6$  and  $F_{small}$  allows us to make the assumption that the dynamics of these time series is

heavily dependent on the same factors. Exploring the forest fires in Russia, the results reached by Solovyev et al. (2004) and Ivanova et al. (2010) pointed to the relationship between the duration of the solar activity cycle and periodicity of fire.

### **Conclusion**

The main goal was to find the functional dependence between the occurrence of forest fires and the factors inherent to solar activity. The results of the rescaled range analysis are shown in the Table 2. The long memory of time series is shown in the R/S analysis with the Hurst-coefficient, but with no correlation between several time series. In other words, the dependence between the number of small fires in the past and small fires in the present was looked for and the work was carried out in all the variables. And it was found that the Hurst-coefficient was near 0.72-0.92, meaning that there was long memory of the number of small fires (such as X6, X7, X8). The 10.7 cm solar flux, (X6) as an indicator of the overall solar activity levels, as well as the maximum daily (X7), i.e. the average daily solar wind speed (X8) point to the necessity of making the prognostic models that will be based on the heliocentric parameters.

When it comes to the correlations between the flow of protons and electrons in different energy ranges and the forest fires in the USA, the results that have been obtained are weak. It is obvious that the experimental laboratory research are necessary to be conducted in order to test the presented values, which at least to some extent could simulate the contact of the charged particles and biomass. In addition, it is necessary to make additional efforts to improve the astrophysical models that would allow understanding the propagation of protons and electrons towards the lower layers of the troposphere. Irrespective of the above guidelines, what can be carried out in a relatively short period of time refers to the making of the prognostic model based on Adaptive Neuro Fuzzy Inference System models.

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