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Study on the Sunspot's Characteristics

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1. Introduction

In the 60's of this century two important theories—fuzzy sets and chaos— are presented, and have been affecting the research of almost all fields of technology. For hundreds of years the behavior of sunspots has been observing and studying. While chaos is widely considered, comparing statistical, fuzzy and chaotic characteristics of sunspots and discussing the relations among them is interesting. The paper, based on the analysis of the possibility, fuzziness and chaos of sunspots, shows that each of statistical, fuzzy and chaotic theories is suitable for analyzing certain aspects of sunspots; sometime combination of these theories is convenient.

2. Possibility in sunspots

The study of sunspot numbers in statistical methods has a long history. As is known, sunspots appear on the light cycle of the Sun. Not only the states of sunspots change continually as time, but also the attribution, the size, the shape and the color of them change very much. Therefore, the possibility of sunspots is of multiple means. The observed data of sunspot numbers play a great role in understanding them. Figure 1.a, 1.b and 1.c show daily, monthly, and yearly sunspot numbers from *Chernosky and Hagan* [1] and consecutive volumes of *J. Geophys. Res.*

From these records, the first impression may be that sunspots time series might not be an exactly periodic one. Hence, in order to understand the solar activity in average mean, statistical methods are convenient. So far, the most popular statistical feature of sunspots is perhaps the 11 year periodicity even though the period of sunspot numbers changes from 9.5 to 14 years. Statistical nature of the solar cycle was not only discussed in regarded to small-scale fluctuation, but also to the large scale. Figure 2 shows the past abundance of carbon-14 assimilation into tree that indicates the Maunder minimum of sunspots(1645--1715)

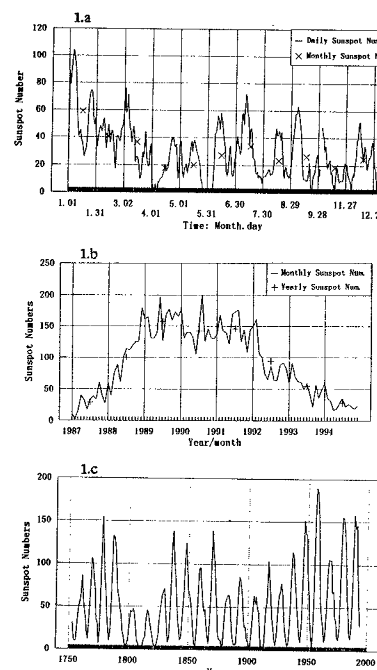

Figure 1. Sunspots time series
1.a daily (1994.1--1994.12)
1.b monthly (1974.1--1994.12)
1.c yearly (1753--1994)

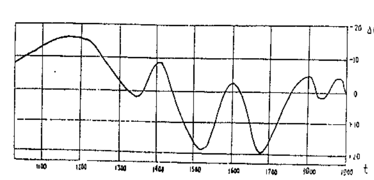

Figure 2. Carbon-14 concentration from tree-ring analysis for period 1050-1990

3. Fuzziness in sunspots

The theory of fuzzy sets starts from the 60's of this century. But the concept of fuzziness appears much earlier. It can be said that at very begin when human beings tried to state natural world, they use a fuzzy way. Though modern science and technology provide us very exact ways to convey different physical objects, we are also used to employing fuzzy way to explain or adjudge certain situations.

In 17 century, sunspots and flares were noted and imaged as that the Sun can emit smoke and soot. As a result, the early records of the sunspots is somehow fuzzy. Today though Sun's activity is observed and recorded in much better ways than that hundreds years ago, the fuzzy appearance of sunspots can not be disregarded too. Zurich classification of sunspots include 9 types that are shown in Figure 3 [2]. It is considered that the state of sunspot types are fuzzy.

When the records of them are transformed to standard sunspot numbers, the following formula (Wolf sunspot numbers) is used:

$$R = k\,(10g + f) \qquad (1)$$

where R is Wolf sunspot numbers; g is the number of groups of sunspots; f is the sum number of sunspots observed; k is a coefficient that depends on the used instruments and observers.

No doubt, the Sun affects the earth so much as we can say. Considering that the Sun is 3.3×10^5 times as big as the earth, the Sun is 1.5×10^8 ㎞ far from the earth, and about 55% of the light from the Sun is reflected or absorbed by the air before it reaches the earth, the relations between the behavior of the Sun and a certain phenomena on the earth will be very confusion and fuzzy. The theory of fuzzy sets may be a useful tool for them.

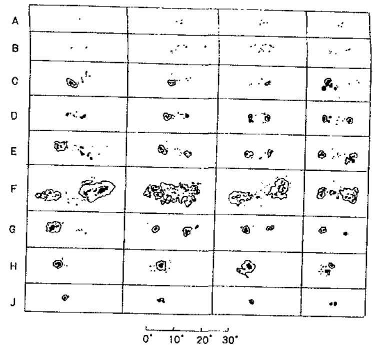

Figure 3. Zurich classification of sunspots

4. Chaos in sunspots

Many studies during recent years have indicated chaotic characteristics for sunspot time series and solar activity. Figure 4 shows the strange attractor of raw and noise- reduced[3] sunspot numbers(1753--1995). The strange attractor of noise-reduced sunspots is in a striking way clear that can not be gotten from raw data. It is also seen that the order of the sunspots cycles does not correspond to the bigness of the cycles. This is supposed to be a general feature of chaotic time series.

Attractor dimensions were calculated according to the algorithm given by *Grassberger* [4]. According to the figure 5, noise-reduced sunspots display saturation at a correlation dimension $d < 2$ [5]. Following the chaotic characteristics of sunspots, Jinno et. al. [6] have developed an updated prediction method of monthly sunspot time series that can predict monthly sunspot numbers in 8 months considerably.

6. Discussion

As mentioned above, sunspot time series possesses possible, fuzzy and chaotic characteristics, and findings have shown that each of the theories of possibility, fuzziness and chaos are effective for analyzing a corresponding feature of sunspots. This follows the fact that the each of these theories generally describes a different aspects of characteristics of things. So far the concept of fuzzy possibility is also used. Long before, the concept of fuzzy chaotic possibility theory should be used somewhere. Therefore, conclusion comes as (1) possible, fuzzy and chaotic theories correspond to different feature of things. They are parallel theories for describing natural phenomena. (2) combination of these theories is need if all or some of these features can not be ignored. (3) The application of possible, fuzzy and chaotic theories in the analysis of sunspot time series is successfull. The methodological idea , which depanding on the prectical situation, apply each or some of possible, fuzzy and chaotic theories to get best answer, can be expanded to other fields.

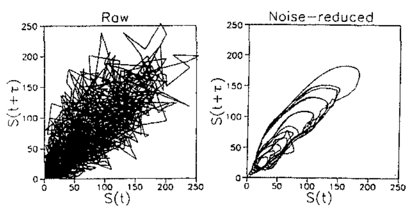

Figure 4. Strange attractor of sunspots (lag time τ =10 months, monthly data)

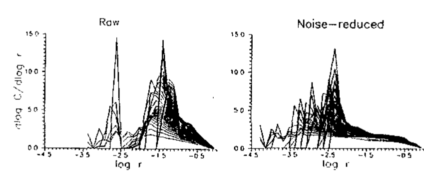

Figure 5. fractal dimension (dlog C/dlog r) of monthly sunspot numbers

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