A Study on Time-Scaling Property of Temperature Events

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Abstract. This study used detrended fluctuation analysis (DFA) and self-organized criticality method to characterize the temporal fluctuations of temperature events of Jiangxi Province. The DFA results show that the temporal scaling behaviors in temperature events. In shorter temporal scaling, it indicates the similar persistence corresponding to the annual cycle. However, in longer temporal scaling, the trends are different for the four series, which reflect the different inherent dynamic nature of various pollutant series. Furthermore, based on the self-organized criticality (SOC), the frequency-intensity distribution of temperature change satisfied Gutenberg-Richter power-law relation. Then, a numerical sandpile model with decay coefficient is constructed to reveal inherent dynamic mechanism of temperature events based on the idea of sand model. The study on occurring mechanism, temporal evolution and inherent dynamic behavior of temperature events, which could provide the scientific basis and important reference for effective establishing all kinds of emergency plan such as extreme weather disaster prevention, mitigation and relief.

1. Introduction
When high temperature events occur, not only the growth and production of some crops are severely restricted, but also directly damages human health. Therefore, in today's society, high-temperature events are receiving more and more attention from all walks of life, and it is widely believed that high temperature events occur, which is negative impacts. So the study on time series of high temperature events has become a hot topic. A number of methods are available in the literature to analyze and forecast the time series, such as Deterministic model [1], Statistical analysis [1-3], Neural networks [4, R/S and Trend analysis [5], Fuzzy mathematic model [6] and SPA technique [7]. In recent, the theory of self-organized criticality (SOC) [8] has been used to understand the power-law scaling and long-term memory of climate change.

Self-organization is a process of internal organization, which increases its complexity without external guidance or management [8-9]. Therefore, if the system does not need to be adjusted by parameters and automatically reaches the critical state, it is called self-organized criticality, which is used to describe the inherent mechanisms of criticality, long-range correlation, $1/f^\beta$ noise and scale invariance (namely fractal) of unbalanced complex systems.

In this paper, the authors examine the temperature events of Jiangxi Province using the detrended fluctuation analysis (DFA), which is widely used for detecting long-term memory and scale-invariance.
Meantime, the sensitivity and reliance of these three methods will be discussed in detail. At last, based on the SOC theory, we analyze the cause of different scale-free power-law behavior for the temperature events.

2. Data
In this paper, Jiangxi Province as the study area (as shown in Figure 1). And the research object is temperature data used percentile threshold method from January 1, 1961 to December 31, 2014. These data come from 83 ground meteorological observation stations in Jiangxi Province and American National Center for Environment Prediction (NCEP) global reanalysis data.

3. Detrended fluctuation analysis of temperature events

The detrended fluctuation analysis (DFA) was proposed by Peng et al. [10], which is an advanced method for determining the scaling behavior of data in the presence of possible trends without knowing their origin. For further detail computation, see References [10].

Figure 1 shows the results of the DFA performed for the temperature events. In the case, we found two different scaling regions with two different DFA exponents, approximately 0.827 and 0.543 for small and large time scales, respectively, with a critical time scale ($n_c$) of about one year. The series is persistent in time spans less than one year and stochastic in time spans greater than one year. On the other hand, they show higher persistence or long-term memory at a large temporal scale in time spans less than one year.

4. Self-organized criticality of temperature events

4.1. The frequency-intensity distribution of temperature events
The frequency-intensity distribution of pollution indexes are found to satisfy power-law relation that is similar to the Gutenberg-Richter law in the earthquakes study [11-12], suggesting there is inherent dynamical connection between small and high events of air pollution, which is one of the most significant signs of SOC behavior[13]. The frequency usually is described as the occurrence of an event exhibits a power exponential drop with the size of the event.

For temperature changes, if they have similar characteristics, the relationship should be satisfied: $N = cr^{-\lambda}$, ie $\log N = \log c - \lambda \log r$, where $c$ is a constant to be determined, $r$ is a temperature intensity value, $\lambda$ is a scale index, and $N$ is the number of temperatures that are greater than a certain temperature intensity value $r$ per year, that is, the temperature above the scale $r$ frequency.
Figure 2 shows the frequency-intensity distribution of temperature events. We find the frequency of temperature events exhibits a power-law decayed distribution with events’ size. The scaling exponent and scale-invariant interval are respectively 1.70 and 0.73 with the least square method. The distribution is a significant Gutenberg-Richter power-law relationship, which is one of the most significant signs of SOC behaviors. Therefore, we believe that the mechanism of occurrence of temperature events in Jiangxi Province has a self-organized critical feature. Moreover, its top is significantly deviated from the linear relationship, mainly because these statistical temperature data ignore huge amounts of low temperature data during a statistical process. A loss of low temperature data lead to deviating off the linear relationship, and the same phenomenon occurs when Peters and Christensen studied precipitation process [14].

Figure 2. The number density of temperature change events per year $N$, with size greater than or equal to $r$, versus change event size $r$ on a double logarithmic scale.

Figure 3. Avalanche size distribution for the sand model of temperature events when $k$=0.01

4.2. The numerical sandpile model of temperature events

After in-depth study and some simplification of the temperature change process, the following algorithm model is established [15-17]:

1. Projecting the urban atmospheric space on the ground surface to form a two-dimensional plane, represented by a two-dimensional square lattice of $L \times L$. (2) It is assumed that in $L \times L$ squares, each time a random temperature value is input to the $1\%$ grid, indicating the change process of the temperature value. (3) In order to indicate the migration and transformation of the temperature value, it is necessary to introduce a "collapse rule". This rule allows the temperature value to be transferred from one square to another adjacent square. (4) In order to express the balance ability of the atmosphere, the temperature value in the input square will decay with time. (5) When a collapse is over, then proceed to steps (2), (3) and (4) to continue the evolution of the system. A series of collapses of various sizes will be formed during the evolution of the system. The main physical quantity studied in the model, the collapse size $s$, is defined as the total number of grids affected by a collapse every time a temperature value is applied. $s$ and its statistical frequency $P(s)$ generally satisfy the power relationship, that is, $P(s) \propto s^{-\alpha}$.

In order to ensure that the calculation has a strict statistical significance, and truly reflect the evolution trend of the numerical sandpile system, two-dimensional $50 \times 50$ grid scale with initial assignment 0 is selected, and a million dual-time stepping are counted when it reaches 100,000 times to start counting. The main aim of initial 100,000 times is to enter critical stable state [18-20].

In the near attenuation $k =0.011$, different $k$ values 0.09, 0.01 and 0.012 are selected for the constructed numerical sandpile model of temperature events and its frequency-intensity relation is simulated. And satisfactory results have been obtained through many parameter debugging calculations. In the double logarithmic degree distribution as shown in the Figure 3, there exist a markedly power-
law relation between collapse size temperature events $s$ and its statistical frequency $P(s)$, which can be described by $P(s) \propto s^{-\alpha}$. Its fitted index or scaling exponent is 7.88, and the scale invariant interval is 0.73. Compared to the Figure 2, we find that the numerical simulation results are in good agreement with the frequency-intensity relation of temperature events, viz. its self-organized criticality be shown significantly.

5. Discussions and conclusions

Summarizing the above results, we elicited the conclusions as follows:

(1) The temperature events series exhibits the persistence or long-term memory, and it obeys two different power laws in shorter and longer temporal scaling regimes. In annual cycle, the scaling behaviors of these four pollution indexes are very similar to each other with very close values for DFA exponent ($\alpha_i$), indicating some similar dynamic characteristics of various temperature events’ temporal evolution. The result shows that it is the same SOC of the atmosphere that drives the evolution of various pollution indexes in one year.

(2) We combined the qualitative and quantitative analysis to explore self-organized criticality of temperature events. Specifically, the Gutenberg-Richter power-law relation of its frequency- intensity relation was firstly authenticated. Then, a numerical sandpile model with decay coefficient is constructed based on the concept of sandpile model. The results have important theoretical significance application value to emergence plans for extreme climate events.

Under the guidance of this theory, we further realize that the heat island effect of the city may directly cause extreme temperature events, and small temperature events may cause extreme temperature events through SOC behavior. Therefore, the focus of people's work in the atmospheric environment should not only be on the rectification of the urban heat island effect, but also on the governance of small temperature events. This study infers that increasing the vegetation coverage rate of the city is equivalent to increasing the attenuation coefficient of temperature events, which can improve the SOC behavior of pollutants and has a positive effect on suppressing the generation of extreme temperatures. Therefore, urban greening projects are of positive significance for suppressing severe extreme temperature events. For the problems caused by these high-temperature events, but due to the large number of large-scale high-temperature incidents, the number of large-scale events, and the improvement of urban greening engineering expediency, the fundamental improvement of urban high-temperature events requires the collective efforts of the whole society.

In addition, the research results also explain from a theoretical point of view why large cities often have more high-temperature events, and small towns tend to have fewer reasons. Large cities are more prone to temperature events than small cities, which is the inevitable result of the self-organized criticality of temperature events.

In short, the study of critical self-organizing behavior of high-temperature events is expected to recognize complex temperature evolution processes from a deeper level and a new perspective. Under the guidance of this new understanding, how to formulate new urban heat island effect control measures will be an issue for environmental workers to think about.

Acknowledgments

This work was financially supported by China Postdoctoral Science Foundation (2016M600515), the Opening Fund of Key Laboratory of Poyang Lake Wetland, Watershed Research (Jiangxi Normal University) Ministry of Education (PK2017002), Jiangxi Postdoctoral Daily Fund Project (2016RC25), the Postdoctoral Preferred Fund of Jiangxi Province (2017KY48), the Open Research Fund of Jiangxi Province Key Laboratory of Water Information Cooperative Sensing and Intelligent Processing (2016WICSIP012), the Key Project of Jiangxi Provincial Department of Science and Technology (20161BBF60061) and the National Natural Science Foundation of China (61703199 and 51669014).
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