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Chaos feature of the time series of the flood and drought areas in China

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ABSTRACT

To quantitatively discover the chaotic dynamic characteristics of time series of the flood and drought areas of China, according to the 61 years of affected area statistical data of the flood and drought, the correlation dimensions of the time series of the flood and drought areas are calculated in the reconfiguration space method. The correlation dimension can be used as valuable index to reflect the disaster characteristics. By the calculation, the correlation dimensions of time series of the flood and drought areas are 0.517 and 0.484 respectively, which shows that droughts are more complex than the floods in China. The results can be applied to further study of the floods and drought features and the prediction of floods and drought of China.

KEYWORDS

Flood area;
Drought area;
Time series;
Chaos;
Correlation dimension.

INTRODUCTION

China is a vast agricultural country, which often suffered from a variety of natural disasters. Floods and droughts are two major disasters. There are many factors to influence the floods and droughts, these interacting factors formed a complex dynamic system. The flood or drought is the result of the combined action of these factors. Many years of disaster loss of floods and droughts is the result of the long-term evolution of the dynamical system inner mechanism. Phase space reconstruction theory opens a new route to research system intrinsic characteristics on the basis of the time series. Existing research shows that flood or drought time series has obvious chaos characteristics[1] , and reconstruction of phase space can restore the strange attractor of chaos. Strange attractor is the final state of long time evolution of chaotic system. Its track is composed of many irregular rotation curves which is complex and disorder, but with self-similarity. Fractal theory can quantitatively calculate the self-similar characteristics of this complex and disorder trajectory, i.e., the correlation dimension. Correlation dimension is one of the most important characters of chaotic system, reflecting the regularity of chaotic systems, and laying the foundation to analysis the formation mechanism of the floods and droughts and predict disaster.

The fractal theory, which is applied to time series research of floods and droughts, has two types. One kind is to regard the time series of flood and drought area as irregular but self-similar characteristic curve, so it has the capacity dimension or information dimension[2] The method can be used to analysis the complexity of the external characteristics of time series of flood and drought area. Another method, which is used in this paper, uses the method of reconstruct phase space to calculation correlation dimension of strange attractor of chaotic systems(Cai, et al. 2005). The fractal dimension in essence is not the fractal dimension of time series, but the fractal dimension of a strange attractor[1,3]. have successfully applied the theory to calculate the correlative dimension of time series of flood and drought areas. Taking the time series of the floods and droughts area on China for example, this paper further discusses the calculation method of the correlation dimension of floods and droughts area series, and analyzes the differences between the correlation dimensions of the floods and droughts area series and the application value of the correlation dimension.

G-PALGORITHM PRINCIPLE

In 1983 Grassberger and Procaccia proposed the G-P algorithm of calculating the attractor correlation dimension based on time series[4-6]. Let { $x_k : k = 1 \cdots n$ } be the time series, where x_k is the observation value at time k. Embed the time series in the m dimension phase space reconstructed, get the set of points:

$$\mathbf{X_n(m,\tau) = (x_n, x_{n+\tau}, \cdots, x_{n+(m-1)\tau})} \quad (1)$$

Where, τ is the time-delay; N_m is the maximum point number; $n = 1, \cdots, N_m$.

The distance of any two points X_i 0 X_j in N_m points is

$$\mathbf{r_{ij}} = \sqrt{\sum_{l=0}^{m-1}\left(\mathbf{x}_{i+l\tau} - \mathbf{x}_{j+l\tau}\right)} \quad (2)$$

For each a $X_i (i = 1, \cdots, N_m)$, one calculates the distance between the point and the rest points. Given a positive r, if distance of two points is less than r, the two points will be called correlation. Let (X_i, X_j) and (X_j, X_i) be the same match, then the number of all possible distance match is $N_m(N_m - 1)/2$. The proportion of the correlative match number in all correlative match number is called the correlation integral, namely

$$\mathbf{C(r) = \frac{2}{N_m(N_m - 1)} \sum_{i=1}^{N_m - 1} \sum_{j=i+1}^{N_m} H(r - r_{ij})} \quad (3)$$

Where, H is the Heaviside step function defined as $\mathbf{H(x) = 0}$ for $\mathbf{x < 0}$ and $\mathbf{H(x) = 1}$ for $\mathbf{x \geq 0}$. Properly adjust the value of r in the range of r, if

$$\mathbf{C(r) = Kr^D} \quad (4)$$

Then it indicates that the distance pairs of points is of statistical scale-free (or self-similarity) in the range. In practice the exponent D should be estimated from the slope in the curve of $\ln C(r)$ against $\ln r$ over a linear region, which gives the numerical estimation of correlation dimension D. Within a small scope of the embedding dimension, correlation dimension increases with the increase of the embedding dimension. When the embedding dimension reaches a certain value, the correlation dimension will tend to a constant value. The constant value of the correlation dimension is the correlation dimension of dynamic system attractor.

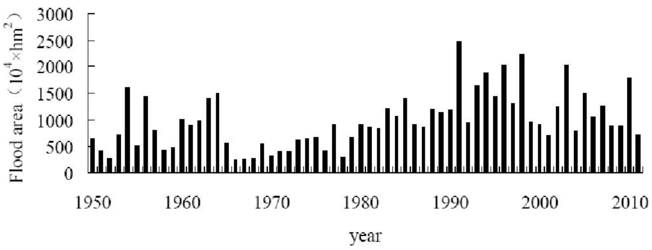
Value of r is dependent on the practice distance of point pairs. If the value of r is too big, being bigger than all of distances of point pairs, then $\mathbf{C(r)}$ must be 1, and $\mathbf{ln(r) = 0}$. The value is not of practical significance which has not reflected the properties of the system. If the value of r is too small, being less than all of distances of point pairs, then $\mathbf{C_m(r)}$ must be 0. The value is also not of practical significance which has not reflected the internal properties of the system as well. Therefore, we should first calculated the minimum distance and maximum distance for each point pairs, then in the range from the minimum distance to maximum distance, select the different values from small to large.

If the attractor exists, when the embedding dimension $m \geq 2D + 1$, the correlation dimension is saturated. Generally from 2, m is gradually increased, until correlation dimension reaches to a stable value. If with the increase of m the D does not tend to a stable value, it indicates that the time series is a random series.

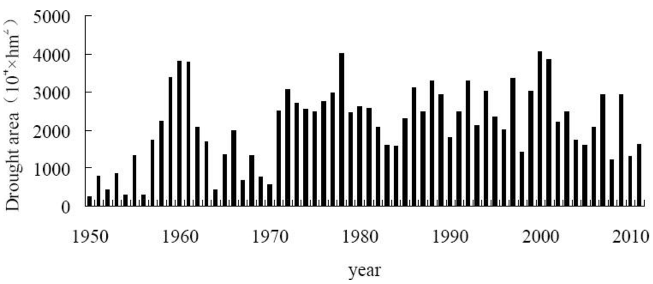
THE CORRELATION DIMENSION OF FLOODS AND DROUGHTS IN CHINA

Basic data

China is a agricultural country in the world, land area 960×10^4km^2, total irrigated area 58.5×10^4km^2, cultivated area 130.1×10^4 km^2. Floods and droughts is one of the most frequent regions in China. The floods and droughts are still the main factors affecting the development of agriculture in the whole country. According to *Bulletin of Flood and Drought disasters in China*[7], the areas of the floods and droughts of China from 1950 to 2011 are shown in Figure 1 (a) and (b) respectively.



(a) flood areas



(b) drought areas

Figure 1 : The flood and drought areas of China from 1950 to 2011

Correlation dimension of flood area series

The minimum distance of points pair of the affected area series is 719.15-718.7 = 0.45× $10^4 hm^2$, the maximum distance of points pair is 2459.6-250.8 = 2208.8×$10^4 hm^2$, so the r meaningful value range is $0.45 < r < 2208.8$. To ensure that all points are in a straight-line segment of $\ln C(r) \sim \ln r$, smaller value r should be taken in the range of r, actually taking r = 5, 10, 20, 35, 50, 100, 200, 400, 700, 1200, 1800. Let $\tau = 1$, $m = 2,3,4\ldots$, $N_m = 40$. From the Figure 2, when m increases to 5, the correlation dimension reaches to a stable value, and the corresponding $\ln r$, $C(r)$, $\ln C(r)$ can be calculated separately, and the results are shown in TABLE 1.

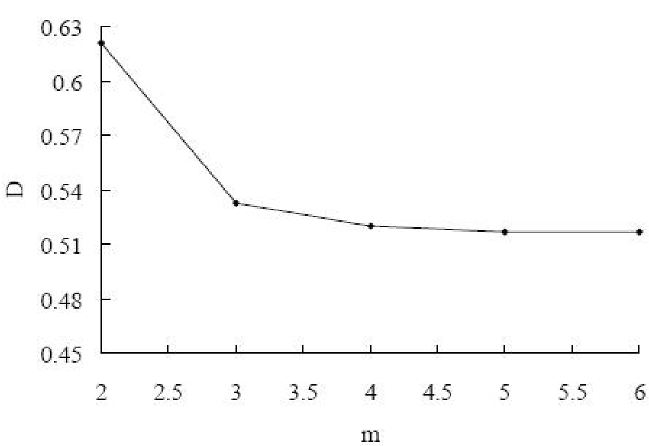


Figure 2 : (a) $m \sim D$ **curve of flood area series**

TABLE 1 : $\ln r$ **and** $\ln C(r)$ **of the flood area series**

Number	r	$\ln r$	$C(r)$	$\ln C(r)$
1	5	1.609	0.025	-3.689
2	10	2.303	0.050	-2.996
3	20	2.996	0.075	-2.590
4	35	3.555	0.100	-2.303
5	50	3.912	0.125	-2.080
6	100	4.605	0.150	-1.897
7	200	5.298	0.175	-1.743
8	400	5.991	0.219	-1.520
9	700	6.551	0.358	-1.029
10	1200	7.090	0.8225	-0.196
11	1800	7.496	1.693	0.526

The linear regression equation of $\ln r \sim \ln C(r)$, i.e., $\mathbf{\ln C(r) = 0.517 \ln r - 4.263}$, is established. The regression curve is shown in Figure 3. From the Figure 3 and the calculated correlation coefficient, $\ln r$ and $\ln C(r)$ can be well suited to linear regression, which indicates that the time series is of fractal characteristics. The slope of the line is 0.517, so the correlation dimension of the time series of flood areas in China is 0.517.

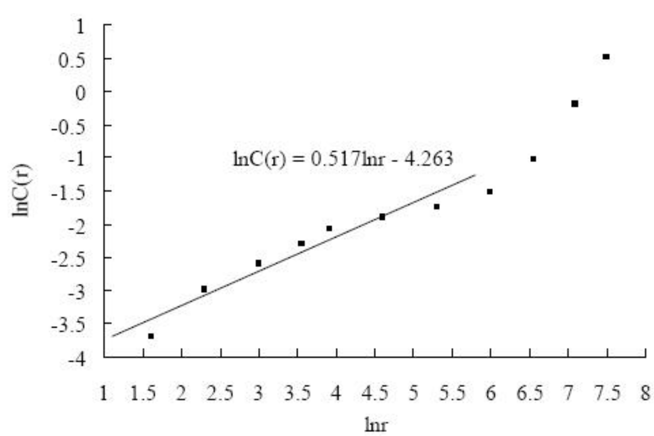


Figure 3 : $\ln r \sim \ln C(r)$ **curve of flood area series**

Correlation dimension of drought area series

The minimum distance of points pair of the drought affected area series is 2492.0-2491.4 = 0.6×$10^4 hm^2$, the maximum distance of points pair is 4054.067-239.8=3814.267×10^{4}hm^2, so the r meaningful value range is 0.6< r < 3814.267, actually taking r = 5, 20, 50, 100, 150, 200, 250, 500, 1000, 1800, 2500 separately. From the Figure 4, when $\tau = 1$, $m = 4$, $N_m = 40$, the correlation dimension begins to a stable value, and the corresponding $\ln r$, $C(r)$, $\ln C(r)$ can be calculated separately, and the results are shown in TABLE 2.

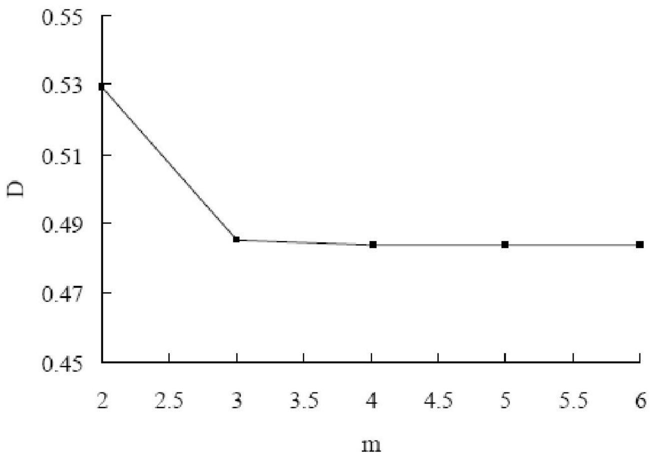


Figure 4 : $m \sim D$ **curve of drought area series**

TABLE 2 : $\ln r$ **and** $\ln C(r)$ **of the drought area series**

Number	r	$\ln r$	$C(r)$	$\ln C(r)$
1	5	1.609	0.025	-3.689
2	20	2.996	0.05	-2.996
3	50	3.912	0.075	-2.590
4	100	4.605	0.100	-2.303
5	150	5.011	0.125	-2.080
6	200	5.298	0.150	-1.897
7	250	5.522	0.175	-1.743
8	500	6.215	0.203	-1.597
9	1000	6.908	0.272	-1.304
10	1800	7.496	0.546	-0.605
11	2500	7.824	1.031	0.031

The linear regression equation of the drought area time series $\ln r \sim \ln C(r)$ curve is established as $\ln C(r) = 0.484 \ln r - 4.472$, shown as Figure 5. Figure 5 indicates that the time series of the drought areas is of fractal characteristics. The correlation dimension of the drought area time series is 0.484.

Chaos feature comparison of flood and drought disaster

The correlation dimension of time series is a number greater than zero and less than 1. The dimension of a point is 0; the dimension of a continuous smooth curve is 1. The plot of disaster area time series is composed of many discrete points, so the dimension of the disaster area time series must be greater than zero and less than 1. Correlation dimension reflects the complexity and roughness of the area time series.

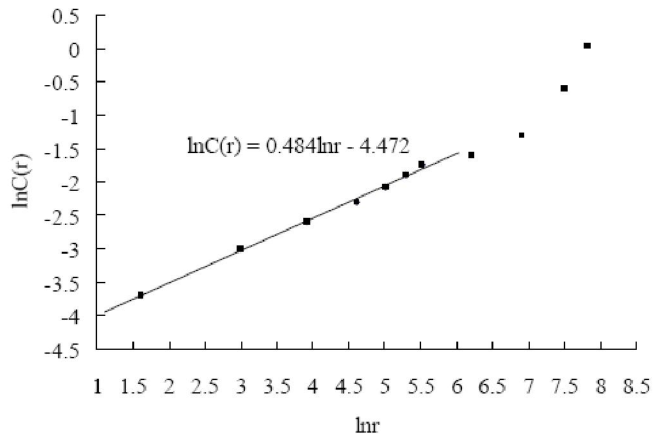


Figure 5 : $\ln r \sim \ln C(r)$ **curves of drought area series**

In the same region, the correlation dimension of the affected area time series of different types of disaster should be different, which reflects different roughness of different types disaster area series. The bigger correlation dimension, the more disparity the affected areas are in different years. Taking China as an example, the correlative dimension of flood area time series is bigger than that of the flood area time series, which indicates that the flood is more intricate than the drought in the region.

Correlation dimension, to a certain extent, can reflect the characteristics of a disaster in a certain region. In a region which has good weather, the correlation dimension of the affected area time series must be smaller, so the correlation dimension can be used to reflect the severity of disasters in different regions.

CONCLUSION

Based on the analysis of the time series of the flood and drought areas of China, the time series of the flood and drought areas have the obvious fractal characteristics. The correlation dimensions of the flood and drought area time series of China are 0.517 and 0.484 respectively, which indicates that the droughts are more complex than the floods in the region.

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Correlation dimension of the affected area time series is a number greater than zero and less than 1. Correlation dimension reflects the roughness and complexity of the affected area series. The bigger the correlation dimension, the more complex the disaster is. So the correlation dimension is a valuable evaluation index for the regional features of flood and drought disaster.

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