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Research Article

Different Multifractal Scaling of the 0 cm Average Ground Surface Temperature of Four Representative Weather Stations over China

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The temporal scaling properties of the daily 0 cm average ground surface temperature (AGST) records obtained from four selected sites over China are investigated using multifractal detrended fluctuation analysis (MF-DFA) method. Results show that the AGST records at all four locations exhibit strong persistence features and different scaling behaviors. The differences of the generalized Hurst exponents are very different for the AGST series of each site reflecting the different scaling behaviors of the fluctuation. Furthermore, the strengths of multifractal spectrum are different for different weather stations and indicate that the multifractal behaviors vary from station to station over China.

1. Introduction

In recent years, a variety of methods such as power spectrum analysis, autocorrelation functions, and detrended fluctuation analysis (DFA), among others, have been widely used to study the correlations and fluctuations of different time series [1–6]. The DFA method as an important technique established by Peng et al. [1] and extended by Bunde et al. [2] and Kantelhardt et al. [7], has been used to detect long-range correlations and determine monofractal scaling properties [7–9]. Moreover, it has been successfully applied to a variety of systems ranging from DNA [1], atmospheric temperature [3–6, 10–13], relative humidity [14], wind speed [15], column ozone [16], and air pollution [17]. However, in DFA analysis to reliably infer the scaling effect, it is necessary to establish power law scaling, investigating both constancy of local slopes in a sufficient range and rejection of an exponential decay of the autocorrelation function [18, 19].

Many studies have shown that a monofractal behavior cannot fully describe uneven multifractal properties [7, 8]. Multifractal theory is an effective method to describe quantitatively the nonlinear evolution of complex climate system and the multiscale characteristics of the physical quantity. Thus, studying the multifractal characteristics of climatic system makes us further understand intrinsic regularity and restriction mechanism of climate change. The theoretical results of multifractal study in the practical application are limited to some extent because the classical estimation method of multifractal spectrum is complicated and difficult [20, 21]. Recently, an extension approach based on the DFA method, namely, MF-DFA, has been applied to analyze the multifractal behaviors of nonstationary time series [22]. It has also been successfully utilized in diverse fields [23–26].

The temperature records as an important climate variable show the fractal feature by taking the self-similar structures containing multiple time scale. There exist monofractal (long-range correlations) characteristics for surface air temperature series over China [27–29]. Moreover, the multifractal behaviors of surface air temperature series have also been studied in the recent years [30, 31]. The DFA method had also been applied in the global mean monthly land and sea surface temperature anomalies during the period

Table 1: Coordinates of the daily AGST sites.

Station	Name	Longitude	Latitude	Start-stop time
56146	Ganzi	100.00°E	31.37°N	Jan. 1951–Dec. 2009
54511	Beijing	116.28°E	39.48°N	Jan. 1951–Dec. 2009
58754	Fuding	120.12°E	27.20°N	Jan. 1953–Dec. 2009
50774	Yichun	128.55°E	47.44°N	Oct. 1955–Dec. 2009

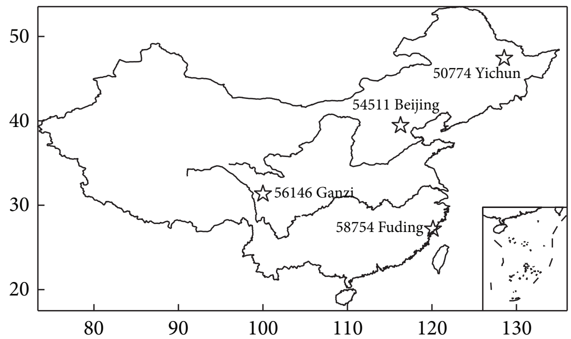

Figure 1: A map of the four selected AGST sites.

of January 1850–August 2008. The results showed that the correlations between the fluctuations in the global mean monthly land and sea surface temperature display scaling behavior which also propagates up to the tropopause [19, 32]. However, the research on multifractal behaviors of the AGST record is less involved due to few sites and short observation data length. The AGST record refers to the temperatures of the ground surface and soil. The record is one of the conventional meteorological observation elements. Thus, it is very important to study the multifractal behaviors of the AGST record.

In the present study, the AGST series is investigated using a powerful technique called MF-DFA [22]. The paper is organized as follows. In Section 2, the method of MF-DFA and the acquisition of the AGST data are described. In Section 3, the comparison of the MF-DFA results for original AGST series with the MF-DFA results for shuffled series and the calculation of the multifractal spectrum are provided. The conclusions are summarized and discussed in Section 4.

2. Methodology and Data

2.1. Methodology Outline. The seasonal cycles from the raw data T_i are removed by computing the AGST anomaly $\Delta T_i = T_i - \langle T_i \rangle_d$, where $\langle T_i \rangle_d$ denotes the average value for a given calendar day. Consider the anomaly time series $\{\Delta T_i\}$, $i = 1 \ldots N$. A generalization of DFA, the MF-DFA method, is briefly described by the following steps [22].

(1) The series $\{\Delta T_i\}$ is integrated to get the so-called profile:

$$y(i) = \sum_{i=1}^{N} \Delta T_i. \quad (1)$$

(2) The profile $\{y_i\}$ is divided into N_s nonoverlapping boxes of equal length s, where $N_s = [N/s]$. Since some data points may be left out, the same procedure is repeated from the other end of the data set. Therefore, $2N_s$ boxes are obtained altogether.

(3) The local polynomial trend $y_\nu(i)$ with order ν for each box is calculated by a least-square fit:

$$y'(i) = y(i) - y_\nu(i). \quad (2)$$

(4) The corresponding variance for each segment length s is given by

$$F^2(\nu, s) = \frac{1}{2N_s} \sum_{k=1}^{2N_s} \left[y(k) - y_\nu(k) \right]^2 \quad (3)$$

for $\nu = 1, \ldots, N_s$. Polynomial detrending of order n is capable of eliminating trends up to order $n-1$.

(5) The qth-order fluctuation function is calculated from averaging over all segments:

$$F_q(s) = \left\{ \frac{1}{2N_s} \sum_{k=1}^{2N_s} \left[F^2(\nu, s) \right]^{q/2} \right\}^{1/q}. \quad (4)$$

If the time series $\{T_k\}$ is long-range power-law correlated, the fluctuation function $F_q(s)$ increases asymptotically with s varying as power law

$$F_q(s) \sim s^{h(q)}, \quad (5)$$

where the exponent $h(q)$ describes the scaling behavior of the qth-order fluctuation function. For monofractal time series which are characterized by a single exponent over all scales, $h(q)$ is independent of q, whereas, for a multifractal time series, $h(q)$ varies with q. This dependence is considered to be a characteristic of multifractal process [22].

A multifractal time series is characterized by calculating the multifractal spectrum $f(\alpha)$ [33, 34]. This singularity spectrum can be related to $h(q)$ via a Legendre transform [26, 33]. The generalized Hurst exponent $h(q)$ and the scaling exponent $\tau(q)$, the singularity exponent α, and the singular spectrum $f(\alpha)$ in multifractal formula have the following relationships:

$$\begin{aligned} \tau(q) &= qh(q) - 1, \\ \alpha(q) &= h(q) + qh'(q), \\ f(\alpha) &= q\alpha - \tau(q) = q[\alpha - h(q)] + 1. \end{aligned} \quad (6)$$

2.2. Data Records. The daily records are processed by the Chinese National Meteorological Information Center (NMIC). The data sets include high-quality daily surface climatic records of 756 Chinese meteorological stations taking part in international exchange. The records have been applied in many studies of climate change in the recent years [26–31, 35–37]. Four representative weather, stations are selected to study temporal scaling properties for daily AGST records. The coordinates and detailed temporal information of the four selected stations are provided in Table 1. The four AGST series are used to study multifractal behaviors in this paper.

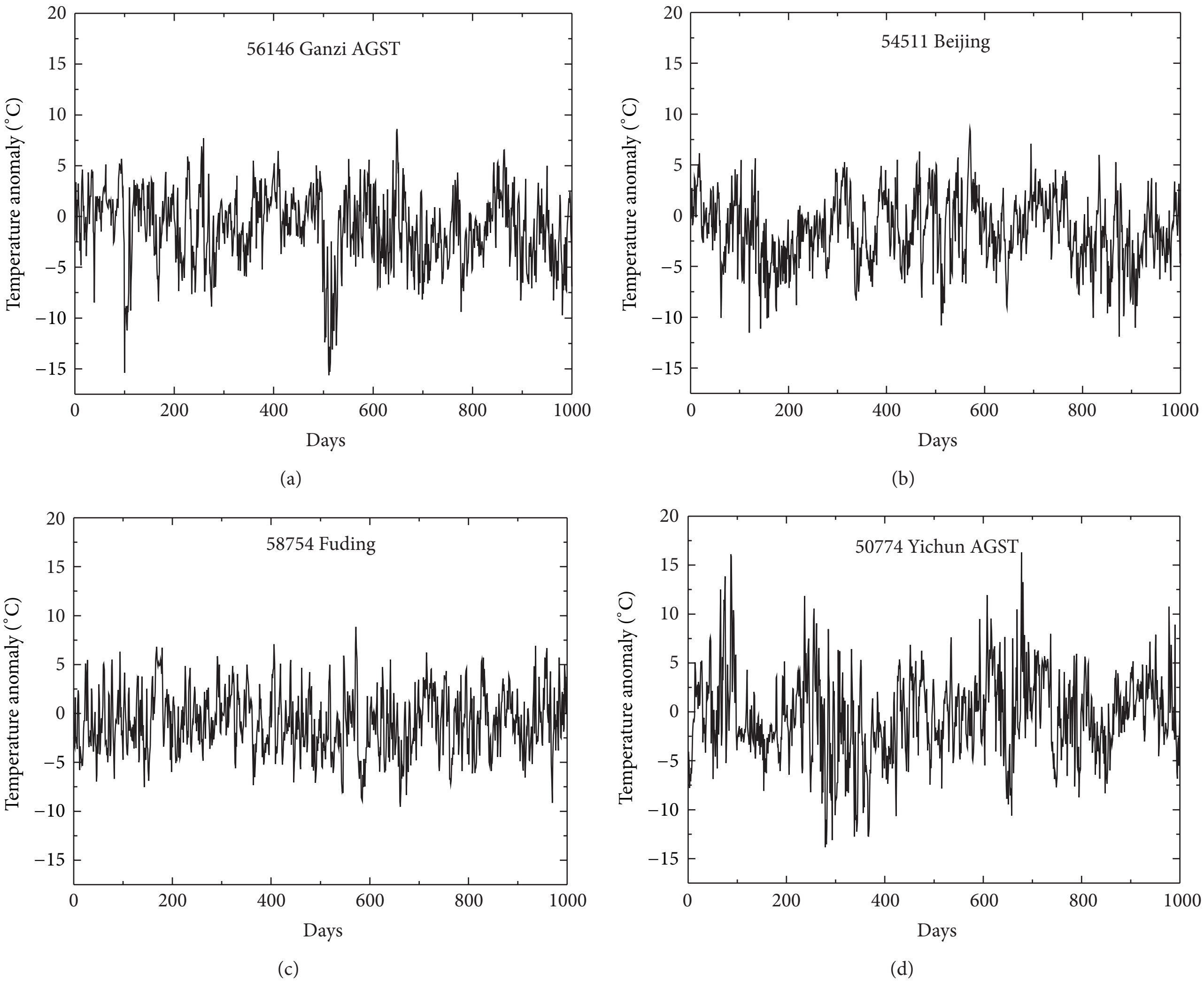

Figure 2: Temporal variations of the four anomaly AGST series for about three years. (a) The station Ganzi in the Southwest of China. (b) The station Beijing in the North of China. (c) The station Fuding in the Southeast of China. (d) The station Yichun in the Northeast of China.

3. Results

The daily AGST records at four representative geographically well-separated locations over China were recorded during the time frame ranging 1951–2009. From Figure 1, it can be seen that the locations are spatially well separated across China. Four selected and representative records, the station Ganzi in the Southwest of China, the station Beijing in the North of China, the station Fuding in the Southeast of China and the station Yichun in the Northeast of China, are used to analyze the three-year temporal trace of the daily anomaly AGST records in Figure 2. As it can be seen from Figure 2, the fluctuation of the AGST records at the station Ganzi and Yichun appears more drastic than that of the Beijing and Fuding records. However, all four time series show irregular high-frequency fluctuations.

The MF-DFA4 method, which eliminates cubic trends in the origin data sets, is applied to analyze the four time series in this paper. The double log plots of the fluctuation function $F_q(s)$ versus s with varying moments ($q = 5, 4, 3, 2, 1, -1, -2, -3, -4, -5$) for the representative records are shown in Figures 3(a), 3(b), 3(c), and 3(d). The q is on behalf of the order of the different amplitude. A negative q value indicates the disturbance in small scale. And a positive q value indicates the disturbance in large scale. For stations Ganzi and Beijing, the slopes of the curve take on the similar shape and become steeper and steeper from the top to the bottom, but the opposite case is for station Yichun completely. Furthermore, the slopes of the curve keep constant on the whole for station Fuding. The curves by the MF-DFA4 do not exhibit same slopes for all ranges in Figure 3. We selected the asymptotic long-range power-law correlations in the range of 300–1000 days, where the scaling is more or less constant for each q, to compute the q dependence of the slope $h(q)$.

In the present study, we calculate the results for all four weather stations in the range of 300–1000 days. Figures 3(e), 3(f), 3(g), and 3(h) show the generalized Hurst exponents $h(q)$ with varying moments ($q = 5, 4, 3, 2, 1, -1, -2, -3, -4,$

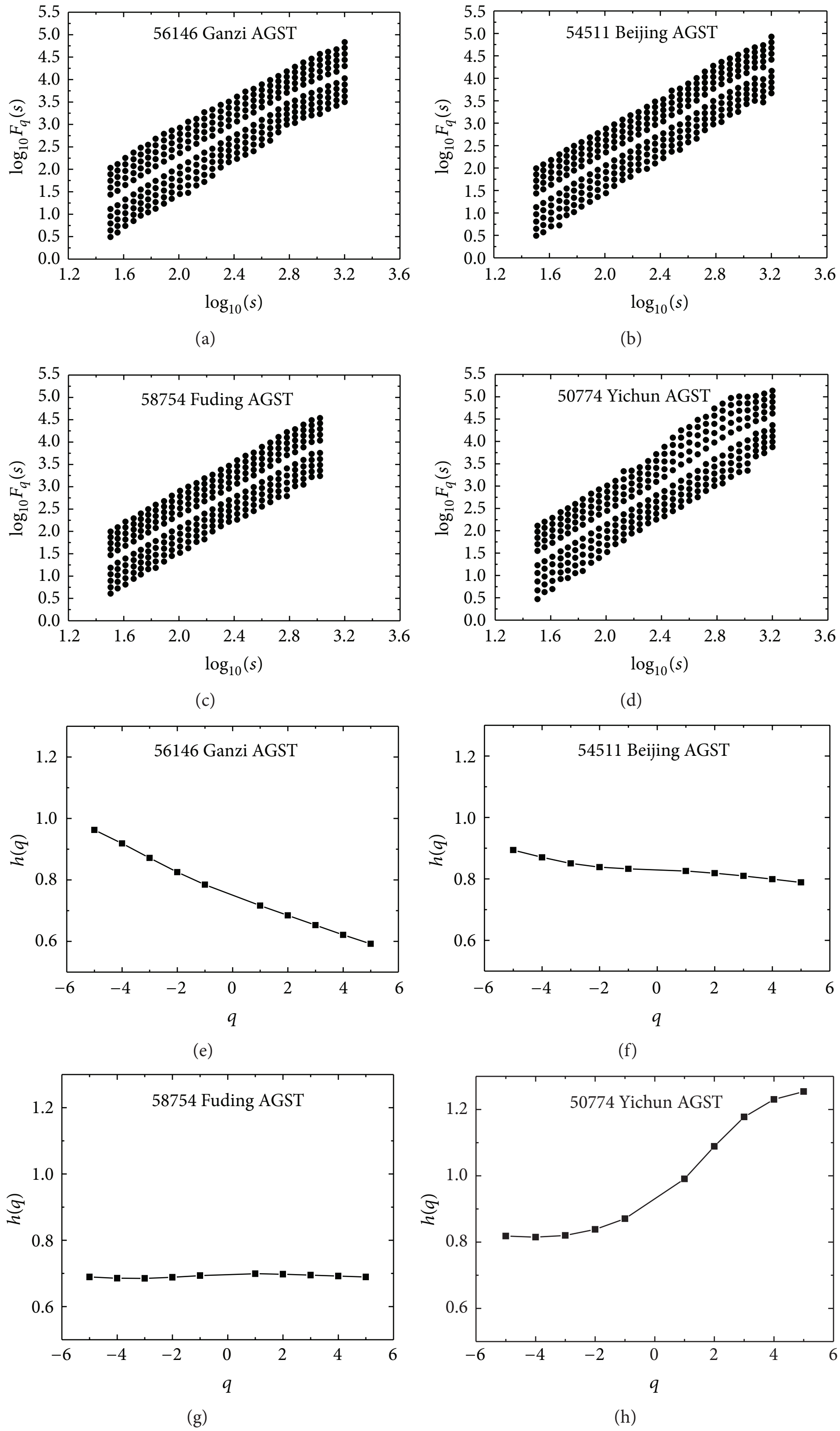

Figure 3: (a) Double log plots of the MF-DFA4 curves of the AGST records for the station Ganzi. From the top to the bottom, curves correspond to different q (from $q = -5$ to $q = 5$). (b), (c), and (d) The analog to (a) but for Beijing, Fuding, and Yichun. (e) $h(q)$ versus q plots for Ganzi. Solid squares: obtained from MF-DFA4 results in (a). (f), (g), and (h) The analog to (e) but for Beijing, Fuding, and Yichun.

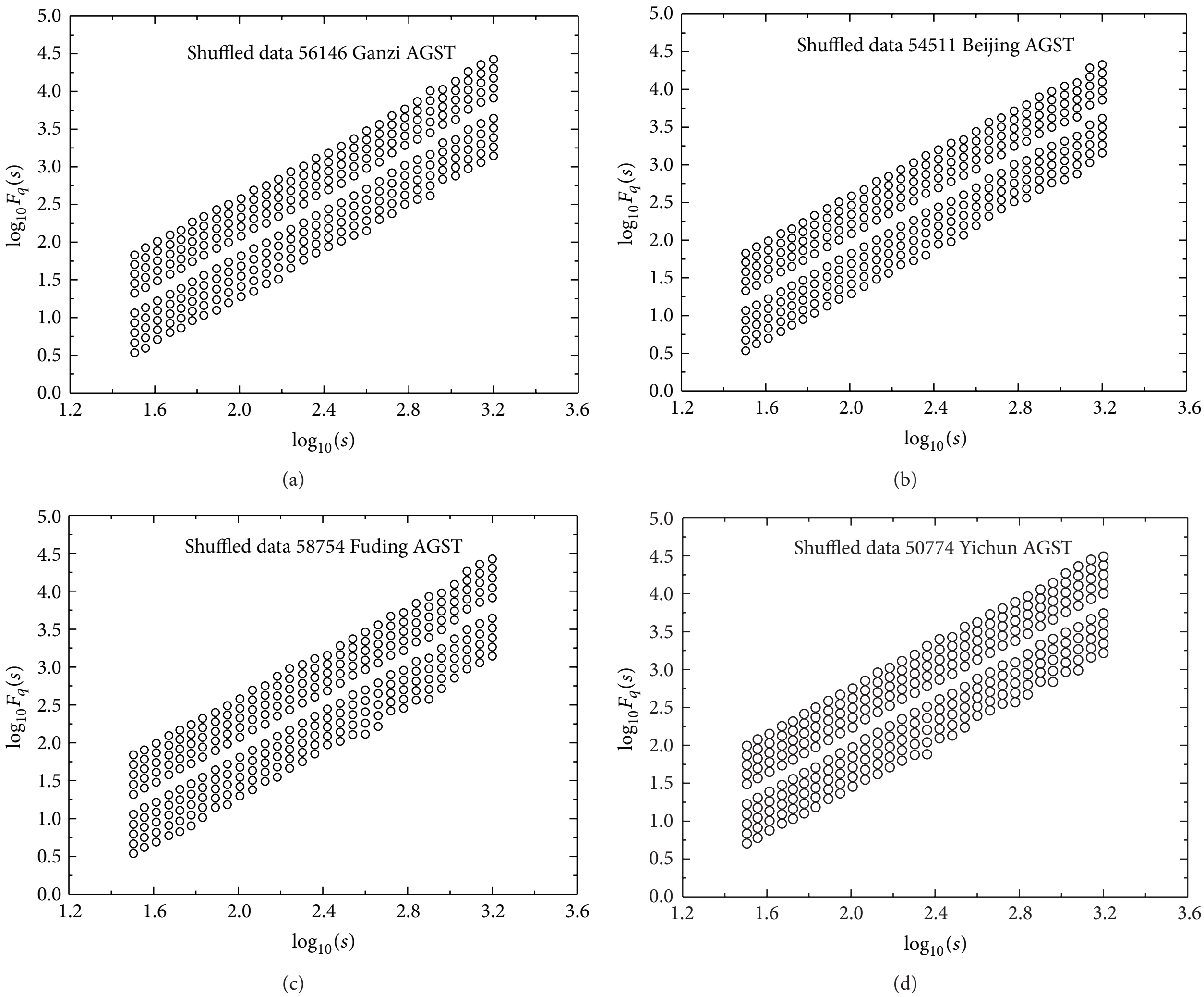

Figure 4: (a) Double log plots of the MF-DFA4 curves for the shuffled data of station Ganzi. From the top to the bottom, curves correspond to different q (from $q = -5$ to $q = 5$). (b), (c), and (d) The analog to (a) but for Beijing, Fuding, and Yichun.

−5) of the daily AGST records for the four sites, respectively. And then we calculate the value $\Delta h = h(-5) - h(+5)$, in which $h(-5)$ reflects the scaling behavior of the smallest fluctuation and $h(+5)$ represents the scaling behavior of the strongest fluctuation. The difference Δh reflects the multifractal phenomenon. The bigger the difference between $h(-5)$ and $h(+5)$, the more obvious the multifractal behavior. By the calculation of the difference value Δh, we find that the fractal phenomenon is very different for the AGST series of each site. It can be seen that the scaling exponents $h(q)$ are greater than 0.5 and less than 1 for stations Ganzi, Beijing, and Fuding in Figures 3(e), 3(f), and 3(g), which indicate the presence of positive long-range power-law correlations. Furthermore, the scaling exponents $h(q)$ decrease with the increase in the moment q which show the multifractal behavior in the AGST records for stations Ganzi and Beijing. While for station Fuding, the scaling exponent changes little indicating the presence of the monofractal behavior. Last, for station Yichun, the scaling exponent $h(q)$ is greater than 0.5 and less than 1 when q is less than 0, which indicates the presence of long-range power-law correlations. The scaling exponent $h(q)$ is greater than 1 and less than 1.5 when q is larger than 0 showing strong persistence between $1/f$ and Brown noise. The difference value Δh for the station Yichun is smaller than 0 and indicates that the long-range correlations of small scale disturbance are weaker than those of lager-scale distribution. The specific mechanism needs further study.

In general, the origin of multifractality is due to a broad probability density function of time series and different long range correlations for small and large fluctuations [18]. By comparing the MF-DFA4 results of the original data sets with those for randomized shuffled surrogates, we can distinguish whether multifractal behaviors are due to the effect of long-range correlations or a broad probability density function. As shown in Figures 4(a), 4(b), 4(c), and 4(d), the fractal behaviors of the four AGST time series are not from broad probability density function since long-range correlations are destroyed by the shuffling procedure and the slopes $h_{\mathrm{shuf}}(q)$ of

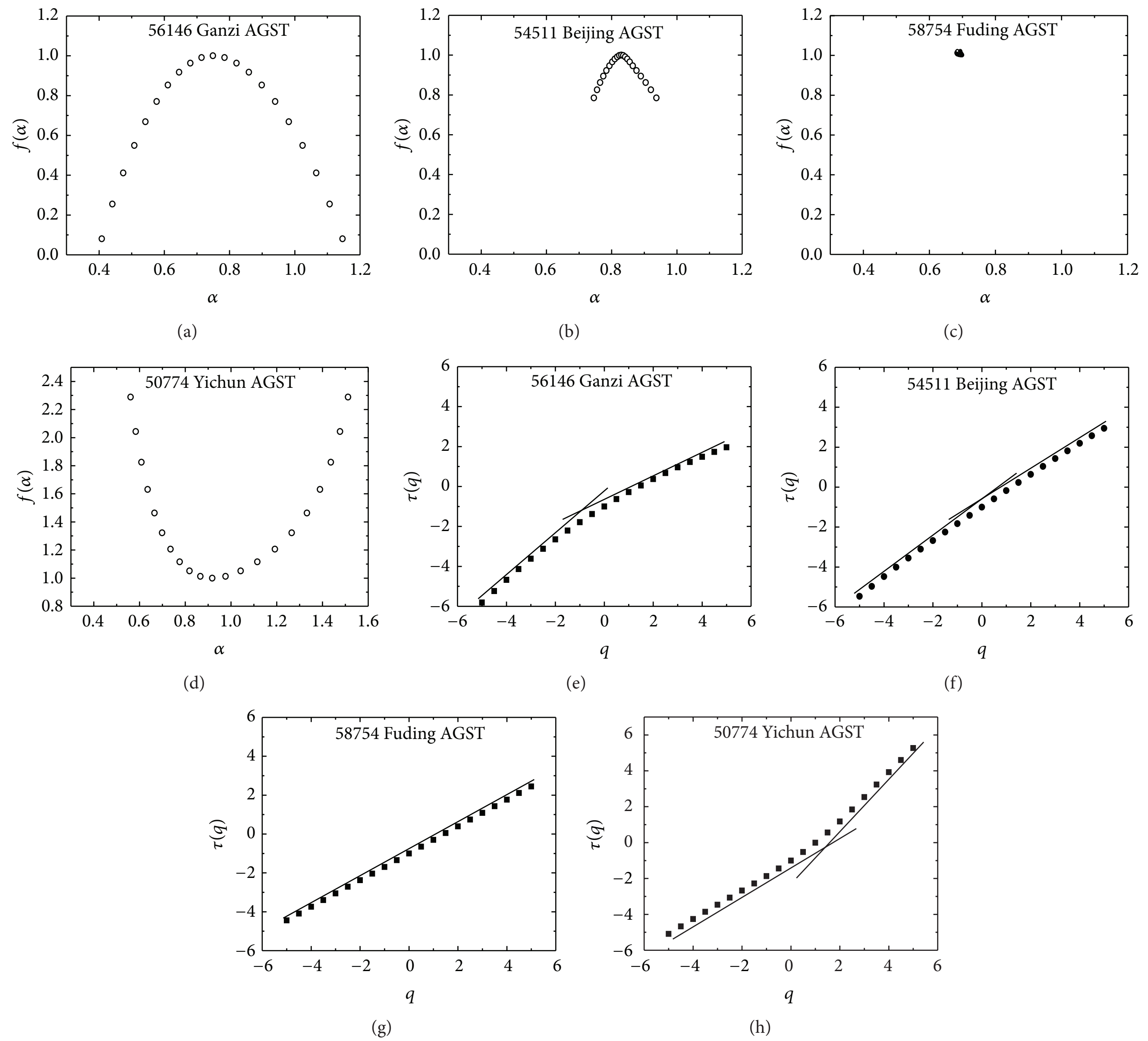

Figure 5: (a) The multifractal spectra $f(\alpha)$ for the AGST record of station Ganzi. (b), (c), and (d) The analog to (a) but for Beijing, Fuding, and Yichun. (e) The scaling exponent $\tau(q)$ for the AGST record of station Ganzi. (f), (g), and (h) The analog to (e) but for Beijing, Fuding, and Yichun.

MF-DFA4, with different orders for the shuffled data over the four selected stations being the same and equal to about 0.5 as random series.

Figures 5(a), 5(b), 5(c), and 5(d) show the relationships between $\tau(q)$ and q of four selected weather stations over China. The nonlinear relationships are shown in Figures 5(a), 5(b), and 5(d) indicating the presence of multifractal behaviors. Figure 5(c) shows that the relationship is linear and proves the monofractal behavior. The fractal exponent α and the singularity spectrum $f(\alpha)$ can be obtained from the generalized Hurst exponent $h(q)$ according to formula (6). Multifractal behaviors can be characterized by calculating $f(\alpha)$ [28, 29].

Figures 5(e), 5(f), 5(g), and 5(h) show the multifractal spectra of the AGST records for stations Ganzi, Beijing, Fuding, and Yichun. It is obvious that the spectra exhibit completely different shapes for the four selected stations. There exist wide distributions of singularity spectrum $f(\alpha)$ values for stations Ganzi and Yichun, while the distribution of $f(\alpha)$ values for station Beijing is little, which implies weak multifractal behavior. For station Fuding, it can be seen clearly that the distribution is concentrated and close to one dot, which indicates the presence of the monofractal behavior. The distributions of singularity spectrum for stations Ganzi and Yichun show the strong multifractal behaviors, while the mechanism affecting the strength of multifractal behavior is different. For station Beijing, the multifractal spectrum shows the weak multifractal behavior. In contrast, the spectrum for station Fuding presents monofractal characteristics. The differences of multifractal behavior for the AGST records may be caused by the different solar radiation intensity and climate system around the different areas over China. But the related atmospheric mechanism is still unknown; these problems need to be discuss further in the future work.

4. Conclusion and Discussion

In this paper, we studied the different multifractal behaviors of the daily AGST records from the four representative weather stations over China using the MF-DFA method. Our main findings can be summarized as follows.

(1) There exist different multifractal behaviors for the daily AGST variations by calculating the differences of the generalized Hurst exponents and it can be identified by power-law relationships. Also the MF-DFA method can be used to calculate multifractal spectrum of complex phenomenon.

(2) The different multifractal behaviors are found for the AGST records over the different areas of China. The strengths of the multifractal behavior seem to be nonuniversal and depend on the geographical location of the station. Many factors may affect the strength of the multifractal behavior. But the origin of the diversity in fractal behavior and related atmospheric mechanism are still unknown; we will discuss these problems further in the future.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

[1] C.-K. Peng, S. V. Buldyrev, S. Havlin, M. Simons, H. E. Stanley, and A. L. Goldberger, "Mosaic organization of DNA nucleotides," *Physical Review E*, vol. 49, no. 2, pp. 1685–1689, 1994.

[2] A. Bunde, S. Havlin, J. W. Kantelhardt, T. Penzel, J.-H. Peter, and K. Voigt, "Correlated and uncorrelated regions in heart-rate fluctuations during sleep," *Physical Review Letters*, vol. 85, no. 17, pp. 3736–3739, 2000.

[3] P. Talkner and R. O. Weber, "Power spectrum and detrended fluctuation analysis: application to daily temperatures," *Physical Review E*, vol. 62, pp. 150–160, 2000.

[4] R. O. Weber and P. Talkner, "Spectra and correlations of climate data from days to decades," *Journal of Geophysical Research D*, vol. 106, no. 17, pp. 20131–20144, 2001.

[5] E. Koscielny-Bunde, A. Bunde, S. Havlin, H. E. Roman, Y. Goldreich, and H.-J. Schellnhuber, "Indication of a universal persistence law governing atmospheric variability," *Physical Review Letters*, vol. 81, no. 3, pp. 729–732, 1998.

[6] K. Fraedrich and R. Blender, "Scaling of atmosphere and ocean temperature correlations in observations and climate models," *Physical Review Letters*, vol. 90, no. 10, Article ID 108501, 2003.

[7] J. W. Kantelhardt, E. Koscielny-Bunde, H. H. A. Rego, S. Havlin, and A. Bunde, "Detecting long-range correlations with detrended fluctuation analysis," *Physica A*, vol. 295, no. 3-4, pp. 441–454, 2001.

[8] K. Hu, P. C. Ivanov, Z. Chen, P. Carpena, and H. E. Stanley, "Effect of trends on detrended fluctuation analysis," *Physical Review E*, vol. 64, no. 1, Article ID 011114, 2001.

[9] Z. Chen, P. C. Ivanov, K. Hu, and H. E. Stanley, "Effect of nonstationarities on detrended fluctuation analysis," *Physical Review E*, vol. 65, no. 4, Article ID 041107, 2002.

[10] R. B. Govindan, D. Vyushin, A. Bunde, S. Brenner, S. Havlin, and H. J. Schellnhuber, "Global climate models violate scaling of the observed atmospheric variability," *Physical Review Letters*, vol. 89, no. 2, Article ID 028501, 4 pages, 2002.

[11] A. Bunde and S. Havlin, "Power-law persistence in the atmosphere and in the oceans," *Physica A*, vol. 314, no. 1–4, pp. 15–24, 2002.

[12] M. L. Kurnaz, "Application of detrended fluctuation analysis to monthly average of the maximum daily temperatures to resolve different climates," *Fractals*, vol. 12, no. 4, pp. 365–373, 2004.

[13] A. Király and I. M. Jánosi, "Detrended fluctuation analysis of daily temperature records: geographic dependence over Australia," *Meteorology and Atmospheric Physics*, vol. 88, pp. 119–129, 2005.

[14] X. Chen, G. Lin, and Z. Fu, "Long-range correlations in daily relative humidity fluctuations: a new index to characterize the climate regions over China," *Geophysical Research Letters*, vol. 34, no. 7, Article ID L07804, 2007.

[15] R. B. Govixdan and H. Kantz, "Long-term correlations and multifractality in surface wind speed," *Europhysics Letters*, vol. 68, no. 2, pp. 184–190, 2004.

[16] C. Varotsos, "Power-law correlations in column ozone over Antarctica," *International Journal of Remote Sensing*, vol. 26, no. 16, pp. 3333–3342, 2005.

[17] C. Varotsos, J. Ondov, and M. Efstathiou, "Scaling properties of air pollution in Athens, Greece and Baltimore, Maryland," *Atmospheric Environment*, vol. 39, no. 22, pp. 4041–4047, 2005.

[18] D. Maraun, H. W. Rust, and J. Timmer, "Tempting long-memory—on the interpretation of DFA results," *Nonlinear Processes in Geophysics*, vol. 11, no. 4, pp. 495–503, 2004.

[19] C. A. Varotsos, M. N. Efstathiou, and A. P. Cracknell, "On the scaling effect in global surface air temperature anomalies," *Atmospheric Chemistry and Physics*, vol. 13, pp. 5243–5253, 2013.

[20] A. Arneodo, E. Bacry, and J. F. Muzy, "The thermodynamics of fractals revisited with wavelets," *Physica A*, vol. 213, no. 1-2, pp. 232–275, 1995.

[21] H. E. Stanley, L. A. N. Amaral, A. L. Goldberger, S. Havlin, P. C. Ivanov, and C.-K. Peng, "Statistical physics and physiology: monofractal and multifractal approaches," *Physica A*, vol. 270, no. 1, pp. 309–324, 1999.

[22] J. W. Kantelhardt, S. A. Zschiegner, E. Koscielny-Bunde, S. Havlin, A. Bunde, and H. E. Stanley, "Multifractal detrended fluctuation analysis of nonstationary time series," *Physica A*, vol. 316, no. 1–4, pp. 87–114, 2002.

[23] K. Matia, Y. Ashkenazy, and H. E. Stanley, "Multifractal properties of price fluctuations of stocks and commodities," *Europhysics Letters*, vol. 61, no. 3, pp. 422–428, 2003.

[24] R. G. Kavasseri and R. Nagarajan, "A multifractal description of wind speed records," *Chaos, Solitons & Fractals*, vol. 24, no. 1, pp. 165–173, 2005.

[25] N. K. Vitanov and E. D. Yankulova, "Multifractal analysis of the long-range correlations in the cardiac dynamics of Drosophila melanogaster," *Chaos, Solitons & Fractals*, vol. 28, no. 3, pp. 768–775, 2006.

[26] T. Feng, Z. Fu, X. Deng, and J. Mao, "A brief description to different multi-fractal behaviors of daily wind speed records over China," *Physics Letters A*, vol. 373, no. 45, pp. 4134–4141, 2009.

[27] G. Lin, X. Chen, and Z. Fu, "Temporal-spatial diversities of long-range correlation for relative humidity over China," *Physica A*, vol. 383, no. 2, pp. 585–594, 2007.

[28] N. Yuan, Z. Fu, and J. Mao, "Different scaling behaviors in daily temperature records over China," *Physica A*, vol. 389, no. 19, pp. 4087–4095, 2010.

[29] L. Jiang, N. Yuan, Z. Fu, D. Wang, X. Zhao, and X. Zhu, "Subarea characteristics of the long-range correlations and the index χ for daily temperature records over China," *Theoretical and Applied Climatology*, vol. 109, no. 1-2, pp. 261–270, 2012.

[30] G. Lin and Z. Fu, "A universal model to characterize different multi-fractal behaviors of daily temperature records over China," *Physica A*, vol. 387, no. 2-3, pp. 573–579, 2008.

[31] N. Yuan, Z. Fu, and J. Mao, "Different multi-fractal behaviors of diurnal temperature range over the north and the south of China," *Theoretical and Applied Climatology*, vol. 112, pp. 673–682, 2013.

[32] C. Varotsos, M. Efstathiou, and C. Tzanis, "Scaling behaviour of the global tropopause," *Atmospheric Chemistry and Physics*, vol. 9, no. 2, pp. 677–683, 2009.

[33] J. Feder, *Fractals*, Plenum Press, New York, NY, USA, 1988.

[34] A. Bunde and S. Havlin, *Fractals in Science*, Springer, Heidelberg, Germany, 1995.

[35] P. Zhai and X. Pan, "Trends in temperature extremes during 1951–1999 in China," *Geophysical Research Letters*, vol. 30, no. 17, pp. 9–4, 2003.

[36] P. Zhai, X. Zhang, H. Wan, and X. Pan, "Trends in total precipitation and frequency of daily precipitation extremes over China," *Journal of Climate*, vol. 18, no. 7, pp. 1096–1108, 2005.

[37] X. Zou, P. Zhai, and Q. Zhang, "Variations in droughts over China, 1951–2003," *Geophysical Research Letters*, vol. 32, Article ID L04707, 2005.