LONG TERM CORRELATIONS AND LACUNARITY OF WIND DIRECTION IN FERNANDO DE NORONHA

Leandro Ricardo Rodrigues de LUCENA[1]
Lázaro de Souto ARAÚJO[2]
Tatijana STOSIC[1]
Moacyr CUNHA FILHO[1]

- ABSTRACT: The complexity of wind direction dynamics at Fernando de Noronha Island, Brazil is analyzed from the point of view of its lacunarity and persistence. We analyze hourly wind direction data recorded over the period 2003-2010. We apply lacunarity analysis that measures the distribution of gaps in dataset on daily wind direction time series in different directional sectors and estimate power-law exponent that describes the rate at which the lacunarity decreases with window length. We also apply Detrended Fluctuation Analysis (DFA) to study temporal correlations in wind direction increments. The results show that the value of lacunarity $L(r)$ for all window sizes, as well the value of power-law exponent are the lowest for prevailing directional sector indicating less clustering and more uniform gaps in wind episodes. The value of DFA exponent α for increment series is greater than 0.5 indicating persistence in wind direction dynamics. These findings should prove useful for developing and validation of theoretical and computational models for wind direction dynamics in Fernando de Noronha, which is crucial for implementation of alternative energy solutions that guarantee sustainable development of this island.

- KEYWORDS: Wind direction; lacunarity; long-term correlations.

1 Introduction

Wind energy plays a strategic role in Brazil's efforts for sustainable development. Brazil is one of thirteen countries involved in the Solar and Wind Resource Assessment (SWERA) project, designed to provide a reliable database in solar and wind energy resources, together with socio-economic, infrastructure and environmental information that enable policy makers to evaluate potential for investments in new renewable energy technologies (MARTINS *et al*., 2007).

The implementation of such technologies will facilitate energy supply in remote areas as in the Amazon region and islands, and help decrease greenhouse gas emissions to

[1] Universidade Federal Rural de Pernambuco - UFRPE, Departamento de Estatística e Informática, CEP: 52171-900, Recife, PE, Brasil. E-mail: *leandroricardo_est@yahoo.com.br; tastosic@gmail.com; moacyr2006@ibest.com.br*
[2] Universidade Federal da Paraíba - UFPB, Centro de Ciências Agrárias, Campus II, Departamento de Ciências Fundamentais e Sociais, CEP: 58397-000, Rod. Pb-079, Areia, PB, Brasil. E-mail: *lazaro.souto@yahoo.com.br*

the atmosphere, by reducing the fossil fuel consumption. The coastal areas of northeastern Brazil are characterized by high potential for wind energy developing programs due to trade wind regime caused by the equatorial Atlantic Ocean (DUTRA and SZKLO, 2008).

The use of wind energy in this region will help regulating energy production during dry season, and preservation of bioenvironmental resources for future generations. Fernando de Noronha archipelago located about 360 km offshore from the Brazilian coast in the Atlantic Ocean, belongs to the state of Pernambuco and is divided in two conservation units: National Marine Reserve (retained for fauna, flora and natural resources protection) and Environmental Protected Area that is reserved for human occupation.

Each of these units has preservation rules that are established by federal and state government with a purpose to preserve natural resources that can be achieved through sustainable development. However, the island energy supply is mainly from diesel generators, which is a serious threat for the environment due to greenhouse gases and particular matter emissions. In order to decrease these emissions recently the hybrid wind diesel system was installed on the island (ROSAS *et al*., 2004).

There is continuous effort in developing efficient technological solutions for energy supply of the island based on wind resources that requires detailed knowledge of wind dynamics at this location. Most of studies related to wind data analysis are concerned with the applicability of various probability density functions to describe wind speed frequency distribution (CARTA *et al*., 2009), however much less work is done on wind direction which is circular variable and thus more complex for statistical analysis (VAN DOOM *et al*., 2000).

On the other hand beside energy generation both wind speed and wind direction fluctuations play important role in modeling of various wind-related phenomena including soil erosion (JONSSON, 1992), air pollution (DEMIRCI and CUHADAROGLY, 2000), pollen and seed dispersal (FRIEDMAN and BARRET, 2009; JONGEJANS and TELENIUS, 2001), evapotranspiration (SKIDMORE *et al*., 1969) etc. One of important characteristics of stochastic process governing spatial and temporal variability of climatic variables as temperature, precipitation, and river discharge is the existence of long-range correlations that are described by power-law, which is a fingerprint of fractal and multifractal processes (EICHNER *et al*., 2003; KANTELHARDT *et al*., 2006).

However there are only a few results on scaling properties of wind speed (GOVINDAN and KANTZ, 2004; DE OLIVEIRA *et al*. 2012), while wind direction, to the best knowledge of the authors, was not studied in this context. In order to contribute better understanding of wind velocity dynamics in Fernando de Noronha which is crucial for evaluation of wind energy potential at this island we analyze correlation properties in daily wind direction time series recorded during the period 2003-2010. We apply Detrended Fluctuation Analysis (DFA) (PENG *et al*., 1994) which was designed to quantify correlations in non-stationary signals. We also apply lacunarity analysis (PLOTNICK *et al*., 1996) that provides information about heterogeneity of wind episodes in a certain direction.

2 Material and method

2.1 Data

The data used in this work are part of a historical climatic database provided by the Center for Time Prevision and Climatic Studies (Centro de Previsão de Tempo e Estudos Climaticos - CPTEC) of the Brazilian National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais - INPE). We chose hourly wind direction time series recorded at Fernando de Noronha Island during the period 01/01/2003 – 12/31/2010. The Fernando de Noronha island located in the Atlantic ocean east of the state Rio Grande do Norte, Brazil (longitude: 32.41 W; latitude: 3.84 S; altitude: 38 m), Figure 1, with area 18.4 km², clime is tropical of type Awi second Köppen classification, the average temperature and precipitation is 25ºC and 1400 mm, respectively (CASTRO, 2010). In recent decades the wind speed potential in Fernando de Noronha island has been extensively studied as reported by: ANJOS *et al*. (2015); FILIPE *et al*., (2010); WACHSMANN and TOLMASQUIM, (2003).

Figure 1- Location of the Fernando de Noronha Island.

The wind rose diagram shown on Figure 2 reveals that prevailing wind direction for this location is Southeast (SE) with 74.9% of total wind direction data belong to this sector.

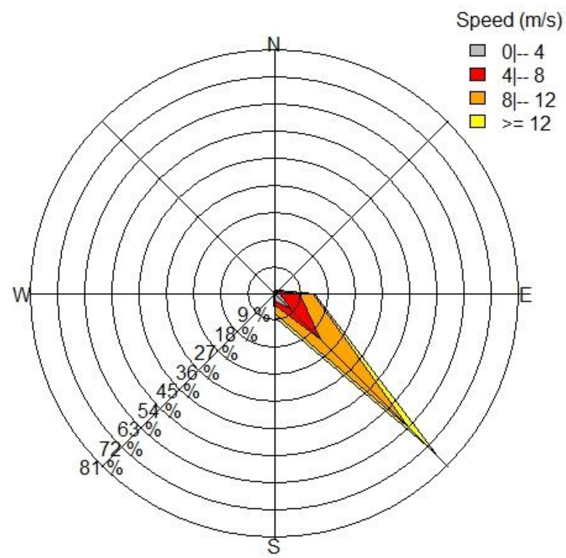

Figure 2- Wind rose for the Fernando de Noronha Station.

2.2 Detrended fluctuation analysis (DFA)

Detrended Fluctuation Analysis (DFA) introduced by Peng *et al*. (1994) is a powerful method for the quantification of correlations in non-stationary time series. This method represents a modified root-mean-square analysis of a random walk, and was successfully applied in physiological processes (NASCIMENTO *et al*., 2010), geophysical signals (VARATSOS *et al*., 2009), climate temporal series (De OLIVEIRA *et al*., 2012), financial data (SIQUEIRA JR. *et al*., 2009), etc.

The implementation DFA algorithm is described as follows. The first step is integration of original series to produce $X(k) = \sum_{i=1}^{k} [\, x(i) - \langle x \rangle \,]$, $k = 1,2,\ldots,N$, where, $\langle x \rangle = 1/N \sum_{i=1}^{k} x(i)$ is the average.

Next, the integrated series $X(k)$ is divided into Nn non-overlapping segments of length n and in each segment $s = 1,\ldots,N_n$ the local trend $X_s(k)$ (linear or higher order polynomial least square fit) is estimated and subtracted from $X(k)$. The detrended variance is calculated as

$$F^2(n) = 1/nN_n \sum_{s=1}^{N_n} \sum_{k=(s-1)n+1}^{sn} [X(k) - X_s(k)]^2. \qquad (1)$$

Repeating this calculation for all box sizes provides the relationship between fluctuation function *F(n)* and box size n. If long-term correlations are present in original series, *F(n)* increases with n according to a power law $F(n) \sim n^{\alpha}$. The scaling exponent α is obtained as the slope of the linear regression of *log[F(n)]* versus *log(n)*.

The value $\alpha = 0.5$ indicates the absence of correlations (white noise), $\alpha > 0.5$ indicates persistent long-term correlations meaning that large (small) values are more likely to be followed by large (small) values, $\alpha < 0.5$ indicates anti-persistent long-term correlations meaning that large values are more likely to be followed by small values and vice versa. The values $\alpha = 1$ and $\alpha = 1.5$ correspond to 1/f noise and a Brownian noise (integration of white noise) respectively (PENG *et al*., 1994; KANTELHARDT *et al*., 2001).

2.3 Lacunarity

The concept of lacunarity was introduced by Mandelbrot (1982) as a measure of the distribution of gap sizes in the fractal object. Geometric objects with gap sizes distributed over a wide range have greater lacunarity than those with smaller and more uniform gaps. Gefen *et al*. (1983) related lacunarity with deviation of a geometric object from translational invariance. Geometric objects with low lacunarity are homogeneous and translationally invariant, while geometric objects that have high lacunarity are heterogeneous and not translationally invariant. Translational invariance is highly scale dependent: the objects that are heterogeneous at small scale can appear homogeneous at higher scale and vice versa. Lacunarity was originally developed to describe properties of fractal objects, but it can be extended on general spatial patterns including those with fractal and multifractal properties and can be used with both binary and quantitative data in one, two and three dimensions (PLOTNICK *et al*., 1996).

Various methods for calculating lacunarity (MANDELBROT, 1982; GEFEN *et al.*, 1983) have been developed. Aamong them, intuitively clear and computationally simple, Allain and Cloitre (1991) gliding box algorithm was extensively used in studies in medicine (DOUGHERTY and HENEBRY, 2001; LUCENA and STOSIC, 2014), ecology (SAUNDERS et al., 2005), climatology (LUCENA *et al*., 2016; LUCENA, 2015; LUCENA *et al*., 2015; LANA *et al.*, 2015; LUCENA *et al.*, 2014; LUCENA and CAMPOS, 2014; LUCENA and STOSIC, 2013; LANA *et al.*, 2010; MARTINEZ *et al*., 2007).

In this work, we apply gliding-box algorithm on one-dimensional set constructed from temporal series of the wind direction. We choose directional sector and we consider each time step as the site that is occupied if wind was blowing within the sector. Figure 3 shows one-dimensional set constructed for prevailing directional sector (SE: 112.5< o <157.5) for Fernando de Noronha data.

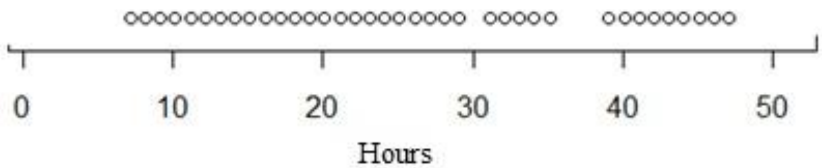

Figure 3 - One dimensional set constructed from hourly wind direction data for prevailing directional sector (SE) for Fernando de Noronha Station.

To characterize the wind direction, the lacunarity is a measure of the distribution of segments, defined as a sequence of consecutive hours that the wind is found in a certain direction, and the gaps defined as sequence of consecutive hours that the wind is not in particular direction. Lacunarity analysis has been used in eight different wind directions. Quantitatively, we have $n(s, r)$ is the number of windows mobile size r(hours) containing s segments (hours is not found in a particular direction). The probability $p(s, r)$ is defined by $\frac{n(s,r)}{N(r)}$ where, the total number of windows of size r is $N(r) = l - r + 1$, and l is the number of time records, including segments and gaps. Then, the lacunarity is defined as the quotient:

$$L(r) = M2(r) \,/\, [M1\,(r)]^2$$

The first and second moment of s is denoted by

$$M1(r) = \sum_{s=1}^{r} s * p(s, r) \text{ and } \quad M2(r) = \sum_{s=1}^{r} s^2 * p(s, r).$$

The lacunarity can be estimated from the following model (MARTINEZ *et al*., 2007):

$$L(r) = \alpha r^{-\beta}$$

3 Results and discussion

Figure 4 shows the result of DFA analysis for amplitude of wind direction increments for hourly wind direction time series recorded in Fernando de Noronha. To avoid artificial large increments which are the result of crossing -180º/180º boundary, we follow the procedure proposed by Van Doorn *et al*. (2000) and calculate corrected increment

$$\forall\ |\Delta\theta| > 180º,\ \Delta\theta \rightarrow \Delta\theta - (\Delta\theta/|\Delta\theta|)360º.$$

The linear behavior between *log[F(n)]* and *log(n*) observed on Figure 4 indicates the presence of long-term correlations in wind direction time series. In order to verify whether the observed power-law behavior stems from long-term correlations or from a wide probability density (KANTELHARDT *et al*., 2001), in Figure 4 we also showed the results of the DFA analysis after shuffling the data.

Figure 4 showed what the original and shuffled series temporal of wind direction had long-term correlations persistent α=0.83 and 0.52, respectively. The fact that the resulting DFA analysis display linear behavior, with slope very close to 0.5 (shuffled series), indicates that the observed power-law behavior in wind direction increment series stems from the temporal ordering of the observations and the associated long-term correlations.

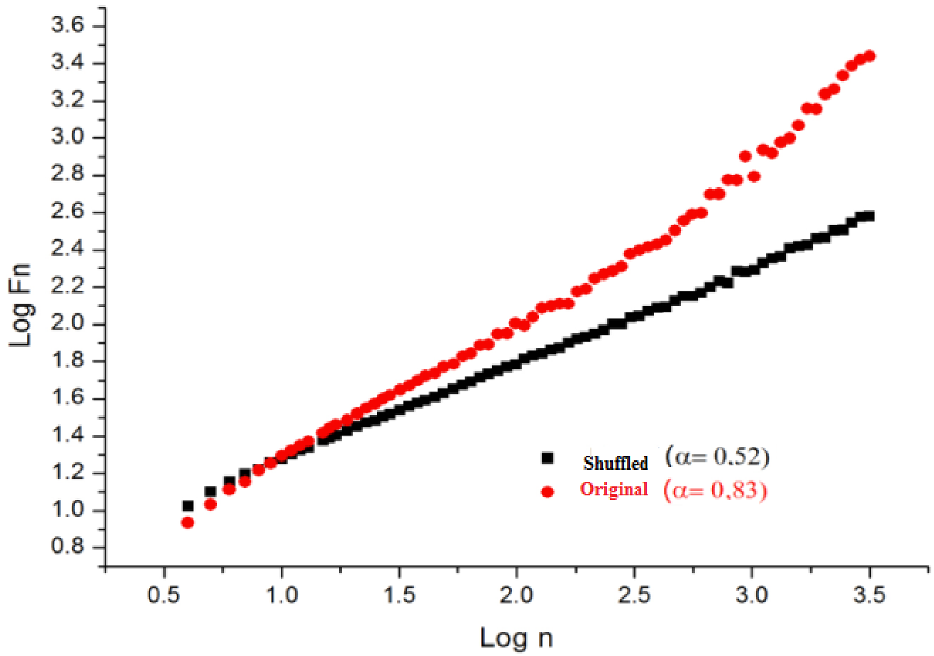

Figure 4- The DFA analysis for the hourly wind direction for the Fernando Noronha station.

The results of lacunarity analysis for wind direction time series recorded in Fernando de Noronha are shown on Figure 5. Observed that smaller lacunarity values are represented in directions E, SE and S, indicating more homogenous distribution these wind directions. In sectors SW, W and NW have highest lacunarity values, indicating greater wind heterogeneity these directions, Figure 5.

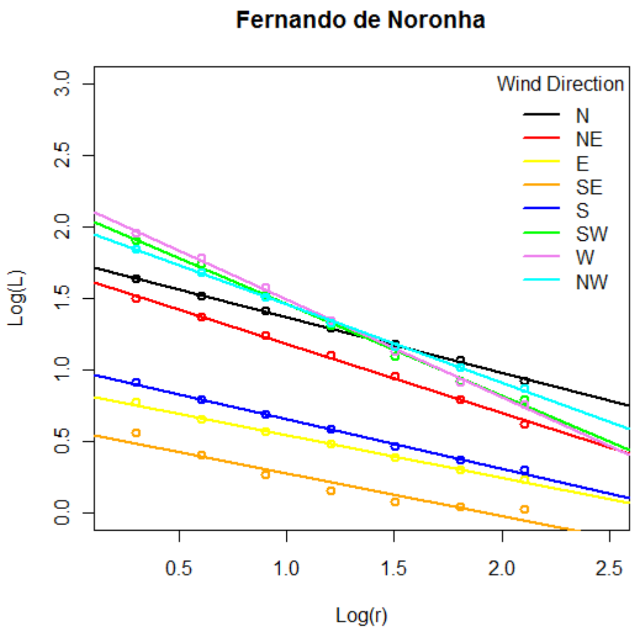

Figure 5 - Empirical lacunarity *L*(*r*) (open circles) as a function of window length *r* for Fernando de Noronha station.

The values of lacunarity exponent's β for all directional sectors (together with a percentage of wind data) and DFA exponent α are presented in Table 1. It is seen from Figure 5 and Table 1 that smaller values of lacunarity exponent's β is represented by sector with highest proportion of wind while highest value exponent is defined by sector with smaller proportion wind.

Table 1- Rate wind direction and β exponent lacunarity of Fernando de Noronha meteorological station

Wind Direction	% wind direction	β
N	1.2	-0.39
NE	1.6	-0.48
E	13.0	-0.30
SE	74.9	-0.29
S	7.8	-0.35
SW	0.5	-0.64
W	0.4	-0.69
NW	0.6	-0.55
	α_{DFA} =0.83	

Conclusions

We apply lacunarity analysis on daily wind direction time series recorded at Fernando de Noronha Island, Brazil, and calculate power-law exponent β that describes the rate at which the lacunarity decreases with window length. Our results show that the value of lacunarity $L(r)$ for all window sizes, as well the value of exponent β are the lowest for prevailing directional sector indicating less clustering and more uniform gaps in wind episodes.

We also apply detrended fluctuation analysis (DFA) to study correlations in wind direction increments. The value of DFA exponent α is greater than 0.5 indicating persistence in increment series, meaning that large (small) values are more likely to be followed by large (small) values, The DFA analysis of shuffled data display linear behavior, with slope very close to 0.5, indicating that the observed power-law behavior in wind direction dynamics stems from the temporal ordering of the observations and the associated long-term correlations.

Results should prove useful for developing and validation of theoretical and computational models for wind direction dynamics and related phenomena in Fernando de Noronha, which is crucial for implementation of alternative energy solutions that guarantee sustainable development of this island.

LUCENA, L. R. R., ARAUJO, L. S., STOSIC, T., CUNHA FILHO, M. Lacunaridade e correlação de longo alcance da direção do vento em Fernando de Noronha. *Rev. Bras. Biom*. Lavras, v.35, n.4, p.645-657, 2017.

- *RESUMO: A dinâmica da complexidade da direção do vendo da ilha de Fernando de Noronha, Brasil é analisada do ponto de vista da lacunaridade e persistência. Analisamos registros horários da direção do vento no período de 2003 a 2010. Aplicou-se a Análise de lacunaridade que mede a distribuição de lacunas no conjunto de dados da série temporal horária da direção do vento em diferentes setores direcionais e a estimativa do expoente de lacunaridade que descreve a taxa na qual a lacunaridade diminui com o comprimento da janela. Também foi aplicada a análise de flutuação retificada (DFA) para estudar as correlações temporais em incrementos da direção do vento. Os resultados mostraram que o valor de lacunaridade L(r) e o expoente de lacunaridade são menores para o setor direcional mais prevalente, indicando menor agrupamento e lacunas mais uniformes nos registros do vento. O valor do expoente DFA para a série de incremento é maior do que 0,5, indicando persistência na dinâmica da direção do vento. Estes resultados devem ser úteis para o desenvolvimento e validação de modelos teóricos e computacionais para dinâmica da direção do vento em Fernando de Noronha, que é crucial para a implementação de soluções de energias alternativas que garantam o desenvolvimento sustentável da ilha.*

- *PALAVRAS-CHAVE: Direção do vento; lacunaridade; correlação de longo alcance.*

References

ALLAIN, C.; CLOITRE, M. Characterizing the lacunarity of random and deterministic fractal sets. *Physical Review A*, v.44, p.3552-3558, 1991.

ANJOS, P. S.; SILVA, A. S. A.; STOSIC, B.; STOSIC, T. Long-term correlations and cross-correlations in wind speed and solar radiation temporal series from Fernando de Noronha Island, Brazil. *Physica A*, v.424, p.90-96, 2015.

CARTA, J. A.; RAMIREZ, P.; VELASQUEZ, S. A review of wind speed probability distributions used in wind energy analysis. Case studies in the Canary Islands. *Renewable and Sustainable Energy Reviews*, v.13, p.933-955, 2009.

CASTRO, J. W. A. Ilhas oceânicas da Trindade e Fernando de Noronha, Brasil: Uma visão da geologia ambiental. *Revista da Gestão Costeira Integrada*, v.10, n.3, p.303-319, 2010.

DEMIRCI, E.; CUHADAROGLY, B. Statistical analysis of wind circulation and air pollution in urban Trabzon. *Energy and Buildings*, v.31, p.49-53, 2000.

DOUGHERTY, G.; HENEBRY, G. M. Fractal signature and lacunarity in the measurement of the texture of trabecular bone in clinical CT images. *Medical Engineering & Physics*, v.23, p.369-380, 2001.

DUTRA, R. M.; SZKLO, A. S. Incentive policies for promoting wind power production in Brazil: Scenarios for the Alternative Energy Sources Incentive Program (PROINFA) under the New Brazilian electric power sector regulation. *Renewable Energy*, v.33, p.65-76, 2008.

EICHNER, J. F.; KOSCIELNY-BUNDE, E.; BUNDE, A.; HAVLIN, S.; SCHELLNHUBER, H. J. Power-law persistence and trends in the atmosphere: a detailed study of long temperature records. *Physical Review E*, v.68, p.046133.1-5, 2003.

FILIPE, D. B. L.; LOBATO, E. M.; QUINTAN, V. C. Energia eólica: análise sobre o potencial eólico brasileiro. *Revista de Divulgação do Projeto Universidade Petrobras e IF Fluminense*, v.1, p.267-278, 2010.

FRIEDMAN, J.; BARRET, S. C. H. Wind of change: ney insights on the ecology and evolution of pollination and mating in wind pollinated plants. *Annals of Botany*, v.103, p.1515-1527, 2009.

GEFEN, Y.; MEIR, Y.; AHARONY, A. Geometric implementation of hypercubic lattice with non-integer dimensionality by use of low lacunarity fractal lattices. *Physical Review Letters*, v.50, p.145-188, 1983.

GOVINDAN, R. B.; KANTZ, H. Long-term correlations and multifractality in surface wind speed. *Europhysics Letters*, v.68, p.184-190, 2004.

INSTITUTO NACIONAL DE METEOROLOGIA. Available at http://www.inmet.gov.br/somabra/maps/automaticas.php.10 Set. 2011.

JONGEJANS, E.; TELENIUS, A. Field experiments on seed dispersal by wind in ten umbelliferous species Apiaceae. *Plant Ecology*, v.152, p.67-78, 2001.

JONSSON, P. Wind erosion on sugar beet fields in Scania, southern Sweden. *Agricultural and Forest Meteorology*, v.62, p.141-157, 1992.

KANTELHARDT, J. W.; KOSCIELNY-BUNDE, E.; RYBSKI, D.; BRAUN, P.; BUNDE, A.; HAYLIN, S. Long-term persistence and multifractality of precipitation and river runoff records. *Journal of Geophysical Research*, v.111, p.D01106, 2006.

KANTELHARDT, J. W.; KOSCIELNY-BUNDE, E.; REGO, H.H.A.; HAYLIN, S. Detecting long-range correlations with detrended fluctuation analysis. *Physica A*, v.295, p.441-454, 2001.

LANA, X.; BURGUEÑO, A.; SERRA, C.; MARTINEZ, M. D. Fractal structure and predictive strategy of the daily extreme temperature residuals at Fabra Observatory (NE Spain, years 1917–2005)**.** *Theoretical and Applied Climatology*, v. 121, p. 225-241, 2015.

LANA, X.; MARTINEZ, M. D.; SERRA, C.; BURGUEÑO, A. Complex behaviour and predictability of the European dry spell regimes. *Nonlinear Processes in Geophysics*, v.17, p. 499-512, 2010.

LUCENA, L. R. R.; STOSIC, T.; CUNHA FILHO, M.; SANTOS, C. R. Análise de lacunaridade de fenômenos climáticos do estado de Pernambuco. *Revista Brasileira de Biometria*, v.34, n.2, p.334-346, 2016.

LUCENA, L. R. R. Lacunaridade como índice de avaliação da precipitação diária do sertão do Pajeú. *Biomatemática*, v.25, p.1-12, 2015.

LUCENA, L. R. R.; STOSIC, T.; CUNHA FILHO, M. Avaliação da precipitação diária do estado de Sergipe utilizando análise de lacunaridade. *Revista Brasileira de Biometria*, v.33, n.2, p.268-276, 2015.

LUCENA, L. R. R.; STOSIC, T.; CUNHA FILHO, M. Análise de lacunaridade de série temporal da vazão dos rios Atibaia e Jaguari. *Revista Brasileira de Biometria*, v.32, n.4, p.609-617, 2014.

LUCENA, L. R. R., CAMPOS, A.C.P. Análise de lacunaridade da precipitação de bacias hidrográficas do estado de São Paulo. *Biomatemática*, v.24, p. 1-8, 2014.

LUCENA, L. R. R.; STOSIC, T. Utilização de lacunaridade para detecção de padrões de imagens de retinas humana. *Revista de Estatística da Universidade Federal de Ouro Preto***,** v. 3, p. 789-793, 2014.

LUCENA, L. R. R.; STOSIC, T. Temperatura do nordeste brasileiro via análise de lacunaridade. *Sigmae*, v.2, n.3, p.76-80, 2013.

MANDELBROT, B. B. *The Fractal Geometry of Nature*. New York: W.H. Freeman, 1982, 468p.

MARTINEZ, M. D.; LANA, X.; BURGUEÑO, A.; SERRA, C. Lacunarity, predictibility and predictive instability of the daily pluviometric regime in the Iberian Peninsula. *Nonlinear Processes in Geophysics*, v.14, p.109-121, 2007.

MARTINS, F. R.; PEREIRA, E. B.; ABREU, S. L. Satellite-derived solar resource maps for Brazil under SWERA Project. *Solar Energy*, v.81, p.517-528, 2007.

NASCIMENTO, R. S.; ARAUJO, L. H. G. D.; MORAES, R. B.; BARBISA, C. T. F.; GUEDES, R. C. A.; NOGUEIRA, R. A.; STOSIC, T. Analysis of signal fluctuations of cortical spreading depression: Preliminary findings. *Physica A*, v.389, p.1869-1873, 2010.

OLIVEIRA, M. S.; STOSIC, T.; STOSIC, B. Long-term correlations in hourly Wind speed records in Pernambuco, Brazil. *Physica A*, v.391, p.1546-1552, 2012.

PENG, C. K.; BULDYREV, S. V.; HAYLIN, S.; SIMONS, M.; STANLEY, H. E.; GOLDBERGER, A. L. Mozaic organization of DNA nucleotides. *Physical Review E*, v.49, p.1685-1689, 1994.

PLOTNICK, R. E.; GARDNER, R. H.; HARGROVE, W. W.; PRESTERGAARD, K.; PERLMUTTER, M. Lacunarity analysis: A general technique for the analysis of spatial patterns. *Physical Review E*, v.53, p.5461-5468, 1996.

ROSAS, P.; LEMOS, W.; PEREIRA, A.; BARROS, R.; FEITOSA, E. Problems of planning wind-diesel power systems. *In: Transmition and Distribution Conference and Exposition: Latin America*, 2004 IEEE/PES: p. 617-22, 2004.

SAUNDERS, S. C.; CHEN, J.; DRUMMER, T. D.; GUSTAFSON, E. J.; BROSOFSKE, K. D. Identifying scales of pattern in ecological data: a composition of lacunarity, spectral and wavelet analysis. *Ecological Complexity*, v.2, p.87-105, 2005.

SIQUEIRA JR., E. L.; STOSIC, T.; BEJAN, L.; STOSIC, B. Correlations and cross-correlations in the Brazilian agrarian commodities and stocks. *Physica A*, v.389, p.2739 – 2743, 2009.

SKIDMORE, E. J.; JACOBS, H. S.; Powers, W. L. Potential evapotranspiration as influenced by wind. *Agronomy Journal*, v.61, p.543-546, 1969.

VAN DOORN, E.; DHRUVA, B.; SREENIVASAN, K. R.; CASSELLA, V. Statistics of wind direction and its increments. *Physics of Fluids*, v.12, p.1529-1534, 2000.

VAROTSOS, P. A.; SARLIS, N. V.; SKORDAS, E. S. Detrended fluctuation analysis of the magnetic and electric field variations that precede rupture. *Chaos*, v.19, p.023114.1-7, 2009.

WACHSMANN, U.; TOLMASQUIM, M. T. Wind power in Brazil – transition using German experience. *Renewable Energy*, v.28, p.1029-1038, 2003.

Received on 10.06.2016

Approved after revised on 16.11.2016