LONG RANGE CORRELATIONS OF OFFSHORE WIND SPEED ON CONTINENTAL PLATFORMS IN THE AMERICAS

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Abstract: Time series records of wind speeds are considered and the general objective is their non-classical statistical analysis on the continental shelf in various locations on the American continent (north, central and south) with the purpose of prospecting the existence of associated power laws as well as long-range correlations and as specific objectives the record of feasibility of local wind generation and description of its behavior. A methodology based on literature review and the use of the DFA (Detrended Fluctuation Analysis) technique is adopted. Data from meteorological stations (onshore and offshore) are used. Finally, preliminary, robust and continuous results show promising aspects and registration of the crossover phenomenon in some situations.

Keywords: DFA. Wind speed. Power Laws.

CORRELAÇÕES DE LONGO ALCANCE DA VELOCIDADE DO VENTO OFFSHORE EM PLATAFORMAS CONTINENTAIS DAS AMÉRICAS

Resumo: Consideram-se os registros em séries temporais da velocidade dos ventos e tem-se como objetivo geral a sua análise estatística não clássica na plataforma continental em diversas localidades do continente americano (norte, central e sul) com fins de prospecção da existência de leis de potência associadas bem como correlações de longo-alcance e como objetivos específicos o registro de viabilidade de geração eólica local e descrição do comportamento do mesmo. Adota-se uma metodologia lastreada na revisão de literatura e uso da técnica DFA (Detrended Fluctuation Analysis). Utilizam-se dados de estações meteorológicas (onshore e offshore). Por fim, resultados preliminares, robustos e contínuos evidenciam aspectos promissores e registro do fenômeno do crossover em algumas situações.

Palavras-chave: DFA. Velocidade do Vento. Leis de Potência.

1. INTRODUCTION

The study of renewable energy sources can be characterized as an emerging science and, in the future, could potentially become one of the main sources of energy, since there are already countries whose official energy plans provide a coverage composed mainly of renewable energy until the year 2030 [1]. Among these clean energy sources, wind energy underwent a rapid expansion on the global stage in the late 20th and early 21st century, as well as its technologies for extraction and exploitation. Thus, this advance represents an opportunity for studies in several areas, such as mechanical, electrical, materials engineering, as well as computer science [2].

Furthermore, with current technology, wind energy can economically compete with conventional energy sources such as coal and natural gas. It is also cheaper than all other renewable energies such as solar, biomass and geothermal [3]. Among the characterizations of this type of clean energy, offshore wind energy can be defined as that whose electricity is produced by wind turbines installed in the ocean or in large lakes, as opposed to onshore energy, in which the turbines are installed on land [2, 4].

Because of this, it is necessary to analyze the energy resources and wind dynamics of a given region, so that it is possible to accurately assess the feasibility of installing a wind farm and, thus, determine the most suitable location for its realization [5].

Therefore, with the above information, the general objective of this research is the analysis of wind speed data obtained through anemometers present in ocean buoys and stations from different locations, in order to verify the behavior of the wind in these regions and thus confirm the existence, or not, of associated power laws and long-range correlations in the action of the winds of these territories.

However, despite observation through equations and laws of physics, such as laws of momentum and conservation of mass and energy, describe large-scale atmospheric disturbances with a good approximation on a short-term basis, with regard to issues related to seasonal weather patterns occurrences and the interaction of general weather patterns, the long-term horizon is implied. Therefore, in order to characterize the types of atmospheric circulation systems in terms of wind speed and direction, and to study their frequencies and interdependencies, some mathematical statistical methods are needed [6].

2. METHODOLOGY

2.1 The DFA technique

In this study, the DFA (Detrended Fluctuation Analysis) method was used to analyze the data from the anemometers and investigate the existence of possible correlations between them. This technique has already been used in research on the dynamics of gene sequences [7], behavior of heartbeat intervals [8] and in the multifractal analysis of precipitation in coastal areas [9]. With this method, therefore,

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it becomes possible to evaluate non-stationary time series and to verify the presence of long-range correlations.

Thus, it is worth considering that to carry out a DFA analysis, four steps must be followed: i) from the original series, the accumulated series is obtained; ii) divide the accumulated series into windows or subsets of size s; iii) remove the local trend in each window through a polynomial fit; and iv) calculate the float function F'(s) in terms of window sizes [7-11].

Thus, this method is primarily based on calculating and graphically representing the accumulated series, similar to a moving average of the data obtained in relation to the time interval of the series, since it is impossible to make a clear analysis from the raw data [7]. For a time series of total length k=1,2,3…N, for example, this moving average can be calculated by calculating the difference between the data obtained for each time instant t and the arithmetic mean of all the data.

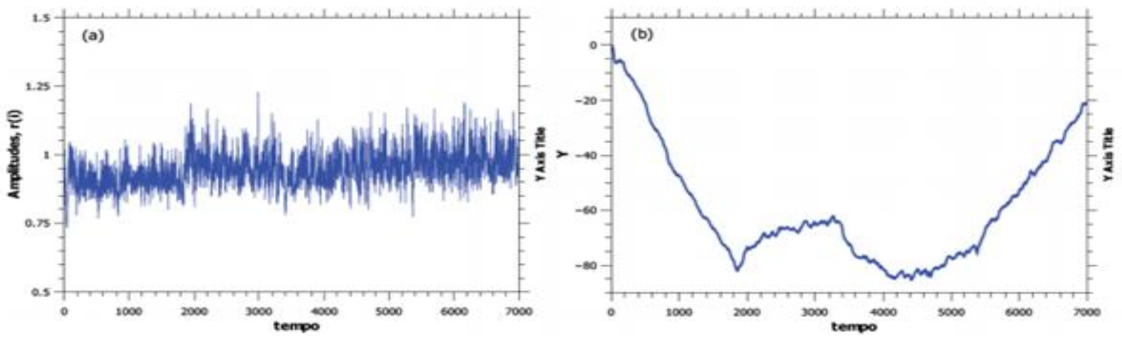
$$\mathrm{MA(k)} = \sum_{t=1}^{k} \mathrm{x(t)} - \bar{\mathrm{x}} \quad (1)$$

The arithmetic mean $\bar{x}$, in turn, is calculated as follows:

$$\bar{x} = \frac{1}{N} \times \sum_{t=1}^{N} x(t) \quad (2)$$

After performing these operations for each possible instant of the time series, a graph can be drawn from the results obtained that can be better analyzed in comparison with the graphical representation of the original time series, as shown in Figure 1.

Figure 1. Time series (left) and moving average (right)

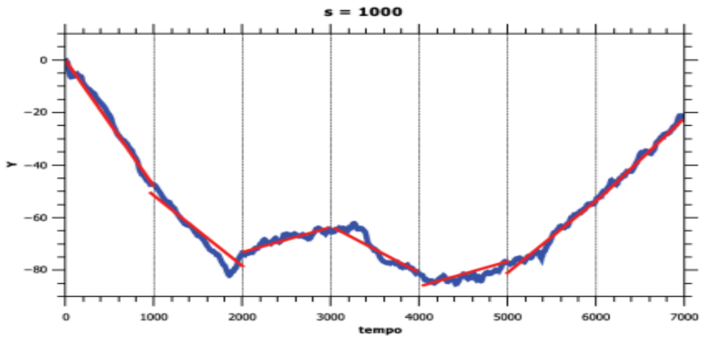


Therewith, the time series is subdivided into a certain number (n) of non-overlapping time segments of length s. Then, the method of least squares is used in order to calculate a linear fit for the data of each interval separately, thus determining the local trend of the function, that is, the behavior of the function in each of these windows.

The least squares method, in turn, consists of determining a function (in the case studied, a first-degree function) for which the sum of the distance between the points obtained by the samples and the line itself is the smallest possible.

The least squares method is a statistical way of evaluating regression analysis to approximate the solution of overdetermined systems [12].

Figure 2. Linear fits for s = 1000.



Afterwards, the function of the accumulated series, calculated previously, must be subtracted by the function of the local tendency found, obtaining a function that will be called $W_s(k)$.

$$W_s(k) = MA(k) - Y_n(k) \tag{3}$$

Thus, it is possible to analyze the “detrended” series, calculating its variance.

$$F_s^2(n) = \sum_{t=1}^{s} W_s(k)[(n-1)s+k] \tag{4}$$

From this equation, one can calculate the average fluctuation function of the time series for the total length N, that is, the total length of all established segments.

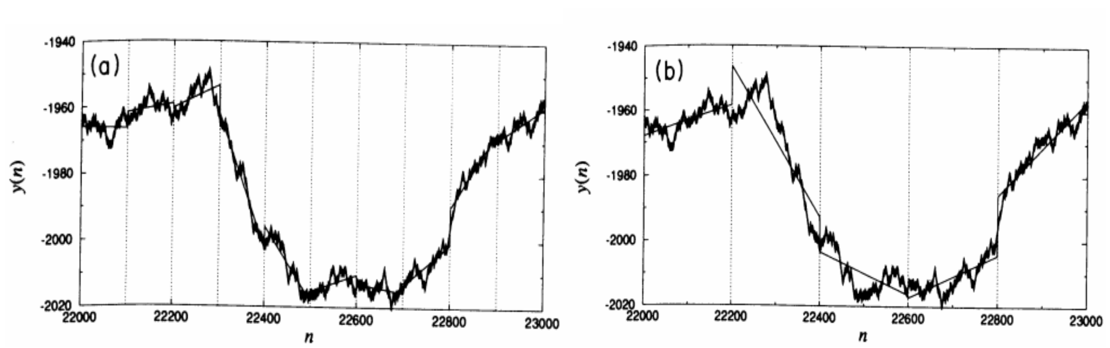
$$F(n) = \sqrt{\frac{1}{N} \times \sum_{n=1}^{N} F_s^2(n)} \tag{5}$$

This equation for the fluctuation can be rearranged as follows:

$$F(n) = \sqrt{\frac{1}{N} \times \sum_{k=1}^{N} [MA(k) - Y_n(k)]^2} \tag{6}$$

Next, it is necessary to repeat this procedure using another scale, that is, adopting other values for the length s of the series segments [7].

Figure 3. DFA Applied in Gene Sequence Studies in (a) for Segments of length $s = 100$ and in (b) for Segments of length $s = 200$.



Thus, a logarithmic scale graph is drawn up for the mean fluctuation values for each analyzed scale and, finally, a linear adjustment in the form $Y = ax + b$.

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Table 1. Characterizations of the Hurst Exponent.

α Values	**Series Characterization**	**Behavioral Description**
0 <α < 0,5	Anti-persistent Behavior	Low values tend to be followed by high values and vice versa
α ≅ 0,5	Random Behavior	There is no correlation in their values
0,5 <α <1	Persistent Behavior	High/low values tend to be followed by high/low values
α ≥1	Anti-persistent Behavior	When α<3/2, there is a subdiffusive behavior
		When α = 3/2 there is a diffusive behavior
		When α> 3/2 there is a super-diffusive behavior

The α present in the fit equation is called the Hurst exponent, and from its numerical value it is possible to characterize the behavior of the series.

2.2 The use of the DFA technique in wind speed analysis

For the analysis of wind speed, the DFA technique was then used on data taken from anemometers located in different locations in the Americas and the oceans, and found at different altitudes, although most of them are located at levels close to the level of the sea.

The periodicity of data collection from these anemometers, in turn, was standardized for all analyzed stations, being collected once every hour. In relation to the chronological horizon observed in each season, this was variable, being no longer than two years nor shorter than approximately two months, between the years 2014 and 2017 [13,14,15].

3. RESULTS AND DISCUSSION

The analyzed data referring to the ocean buoys found in the Atlantic Ocean were taken from the PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) project database, while those referring to the buoys located in the Indian and Pacific oceans belong, respectively, to the RAMA (Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction) and TAO (Tropical Atmosphere Ocean) projects. The data from the station located in Ondina, in the city of Salvador, BA, in turn, were taken from the meteorological station of this location [12, 13]. Regarding data from other stations, these are controlled and made publicly available by the NDBC (National Data Buoy Center).

Table 2. Scale Exponents for the Stations Analyzed.

Numbers of the Stations	**Location**	**Coordinates**		Geographical Elevation (m)	**Scale Exponent Values**				**Analyzed Time Interval**
		Latitude	Longitude		Hourly Average				
					Crossover 1		Crossover 2		
					α_1	σ_1	α_2	σ_2	
1	**Station Shell West Delta 143**	28°39'42" N	89°33'5" W	0 m	1,00	0,01	1,07	0,03	2016-06-15 to 2016-04-09
2	**LUMCON Marine Center, LA**	29° 15'18 "N	90° 39'49" W	1 m	1,21	0,01	0,77	0,03	2016-01-03 to 2016-05-30

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3	**Atlantic Ocean (PIRATA)**	10º S	10º W	0 m	1,21	0,04	0,61	0,01	2016-03-13 to 2017-01-01
4	**Atlantic Ocean (PIRATA)**	0º N	23º W	0 m	1,01	0,01	-	-	2016-01-01 to 2017-01-01
5	**Indian Ocean (RAMA)**	8º S	95º E	0 m	1,21	0,01	1,00	0,01	2017-01-01 to 2018-01-01
6	**Pacific Ocean (TAO)**	8º N	170º W	0 m	1,00	0,01	-	-	2001-01-01 to 2001-10-19
7	**Ondina, Salvador, BA**	13° 0'21.40"S	38°30'33.30"W	10 m	1,24	0,08	0,56	0,08	2014 to 2016
8	**Portland Island, AK**	58° 20'47 "N	134° 45'8" W	3 m	1,11	0,01	0,84	0,01	2016-01-01 to 2016-12-30
9	**Portlock Bank**	57° 56'51 "N	150° 2'30" W	0 m	0,77	0,02	0,73	0,01	2016-01-01 to 2016-10-01
10	**Stannard Rock Lighthouse**	47° 11'1 "N	87° 13'30" W	178 m	1,33	0,04	0,76	0,03	2017-09-08 to 2017-10-24

Thus, the existence of different power laws for the analyzed cases is observed, detecting, in some of them, the crossover phenomenon, that is, a change in the behavior of the time series identified by the presence of correlations with power laws in two regions of distinct scales (subdiffusive and persistent) for the time series [13,14,15].

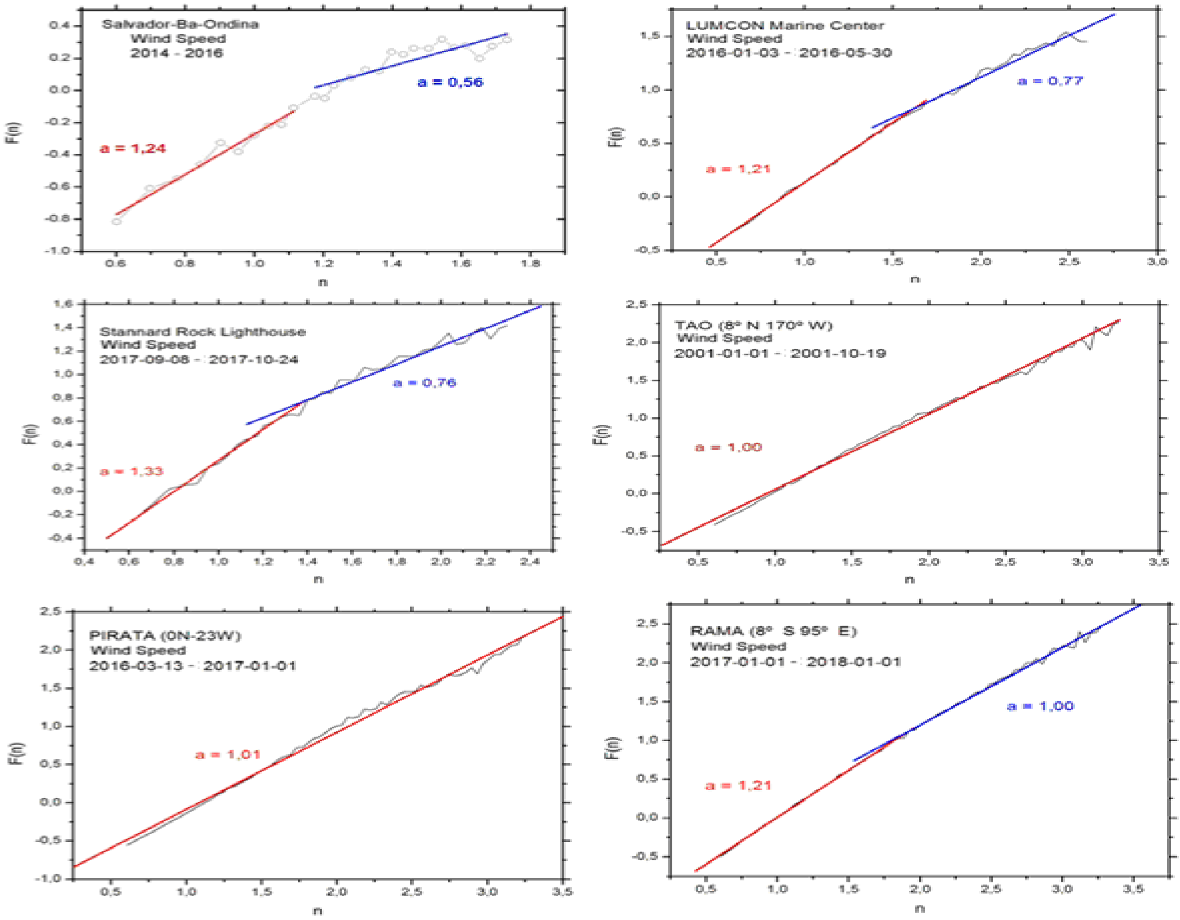
In these cases, the existence of a subdiffusive behavior is predominant before the crossover, while after the crossover long-range correlations are identified, characterizing a persistence behavior, with large (small) values tending to be followed by values, equally, large (small), as shown in Figure 4.

So, the existence of crossover in stations located in internal territories of the continent is noticed, both for regions of South America and for North America. Conversely, it can be seen that in stations located offshore, in general, the observed behavior does not show crossover, being completely subdiffuse both for stations present in the Atlantic Ocean and for those located in the Indian and Pacific Oceans. The only exception, in this case, is the buoy of station number 4 analyzed, as it is located close to the so-called Mid-Atlantic Ridge.

The mid-ocean ridges are the largest mountain ranges of great geological importance and the most active volcanic systems. Mid-ocean ridges are essentially dissemination centers where two oceanic tectonic plates separate. As the plates move away from each other, molten rock emerges from great depths. Some molten rocks rise to sea level, producing volcanic eruptions and long volcanic chains. Magma that reaches the sea floor freezes and solidifies, forming divergent plate boundaries and creating a new oceanic crust. The Mid-Atlantic Ridge, which extends along the center of the Atlantic Ocean, is one of the best-known divergent boundaries [16, 17].

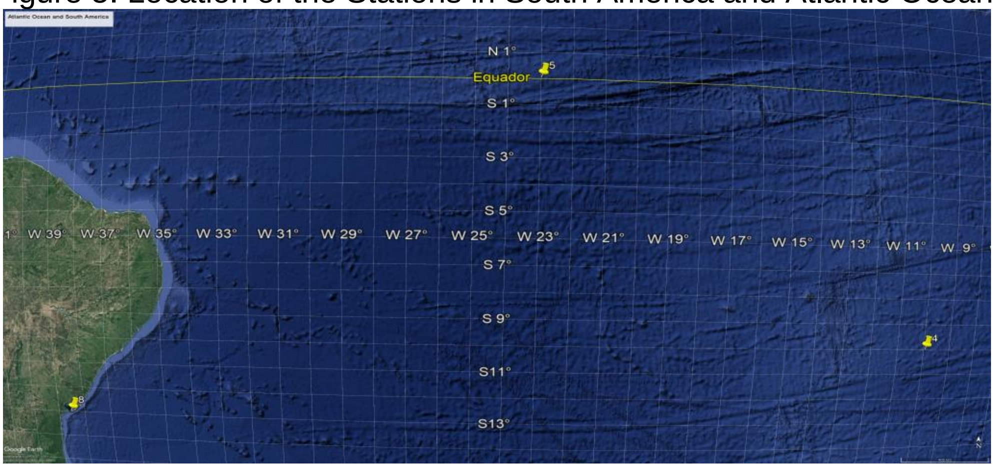
Thus, crossover present in the time series of this station can be explained by the high seismic and volcanic activity of the region in which it is located, in addition to the considerable amount of islands present in this location, as a consequence of the great seismic activity coming from the Mid-Atlantic Ridge.

Figure 4. Records of the fits coefficients in DFA of the stations.



Therefore, in general, these analyzes graphically demonstrate the presence of crossover in continental areas, as well as its inexistence in places far from the coast, such as in open sea areas.

Figure 5. Location of the Stations in South America and Atlantic Ocean.



It is also not possible to observe the occurrence of crossover phenomena in the series that represent data from stations 1 and 9. These stations are located respectively on the continental shelf north of the Gulf of Mexico and on the continental shelf of the western portion of the North America (near the coast of Alaska).

Figure 7. Location of the Stations Near the Gulf of Mexico.

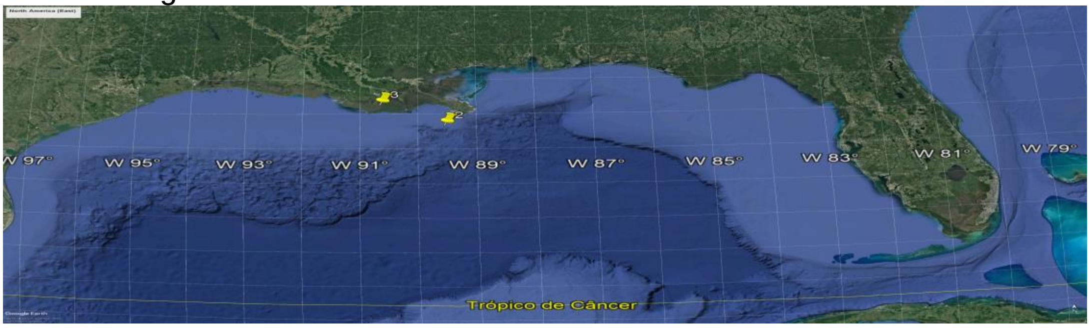
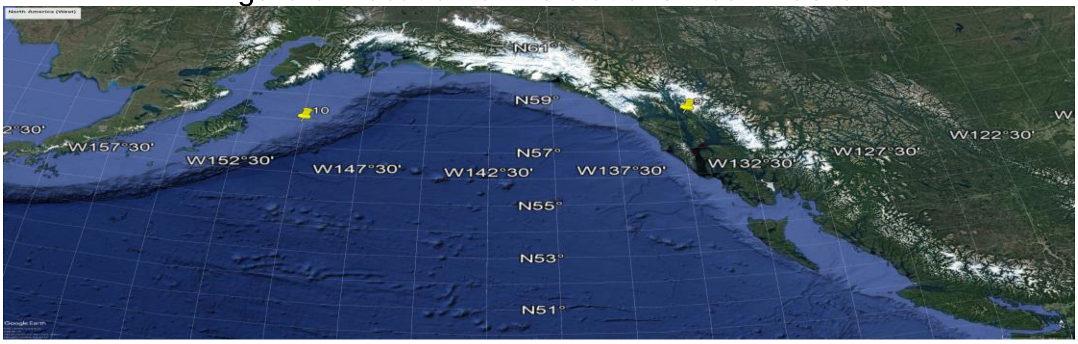


Figure 8. Location of the stations Near Alaska.



Among these, the first presents a subdiffusive behavior while the last one, in turn, presents a persistent behavior. Those distinct behaviors are possibly due to the difference in the proximity of each of these stations to continental areas or islands, in addition to certain relief characteristics of the surface where each one is located.

4. CONCLUSION

This identifies, therefore, a possible relationship between the presence and intensity of the crossover with factors and characteristics of the local terrain, such as roughness, distance from the sea, elevation, orography and even urbanization, in addition to the fact that these data under analysis confirm results of previous works [13, 14, 15] which allows the generalization of the phenomenological explanations put forward by them.

Furthermore, it is concluded that the behavior of a time series, obtained through the DFA, can indicate the wind potential of a location, so that persistent series designate a constancy in the behavior of the winds, being favorable for eolic energy generation, while the subdiffusive series, contrarily, express an unfavorable inconstancy in this regard [14]. Thus, it is also ratified the reliability and applicability of the methodology used for anemometric analysis and, consequently, for studies related to wind power generation.

It is also worth considering that from the analysis of the observed data, it is also confirmed that the crossover phenomenon tends to appear and increase in intensity as the distance to continental territories or with the presence of islands decreases as well as its correlation function with irregular terrains or areas with great presence of urbanization, which indicates providential and promising results for new analyzes already underway.

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