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Wind Speed Study and Persistence Analysis for a Set of 18 Weather Stations Located on the Colombian Caribbean Region

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Abstract : A wind behavior study was carried out on the Colombian Caribbean Region using data recorded by the Colombian Hydrology, Meteorology, and Environmental Studies Institute (IDEAM) from 2003 and 2013. In order to provide an analysis of the existing wind potential in the Colombian Caribbean region, sensitizing the rational use of energy from renewable energy sources and not depending on the use of sources of energy conversion due to the burning of hydrocarbons which Affect the environment. The study involved a statistical analysis of the wind speed behavior using the auto correlation function and wind persistence, for the stations located in the Departments of Atlántico, Bolívar, Cesar, Córdoba, La Guajira, Magdalena, Sucre, San Andrés y Providencia. Obtaining by means of illustrations and data analysis the behavior of wind speed, wind direction and the persistence of wind in the studied stations.
Keywords : Auto correlation function, wind persistence, wind roses, wind speed, wind persistence, weather stations.

Introduction

The Colombian Caribbean Region is currently experiencing a situation where the power service sustainability depends upon the power plants such as thermoelectric power plants that contributes with 30.8% of the power generation service, the hydroelectric power plants with a contribution of 64% and 4.8% from other power generation sources, these being the main power generation sources in the country, which are having issues to supply the current power demand needed for domestic and commercial applications, which is around 65,000 GWh. Furthermore this sources produce contamination due to the emissions by the burning of fossil fuels. And also, the changes of the main riverine water bodies in Colombia, due to its use as source for hydro power generation [1].

Some Departments of the Colombian Caribbean Region are in a state of emergency due to the high levels of poverty, lack of public utilities, and a great deal of geographical space with sources of power generation being wasted away. Aiming to technology development, jobs generation, and enhancements on common wealth, the trend of the studies emphasizing on power efficiency and rational use of power, highlight the use of clean energies such as solar and wind energy as means of power generation, as it was pointed out by the Colombian Ministry of Mines and Energy (MINMINAS) that seeks to foster the development and use of unconventional power sources such as wind energy is, this with the approval of Law 1715 of 2014, "Law that regulates the integration of unconventional renewable energies to the National Grid System", also Decree 1623 of 2015 "Decree that modifies and adds Decree 1073 of 2015, regarding the definition of the policy guidelines for the expansion of the power service coverage to the National Grid and the off-grid zones".

On 2002 the first Wind Energy Farm of the Colombian Caribbean Region called Jepirchí located in the Department of La Guajira was built, it was commissioned on 2004 with an installed capacity of 19.5 MW providing 0.1% of the power needs for Colombia. In 2010 the license was granted for the construction of an energy wind farm called Jouktai at El Cabo de la Vela, with capacity of 31.5 MW, the approval of the Act 1715 of 2014 has increased the records for similar type projects at the Mining and Energy Planning Unit (UPME).

The aforementioned encourages the need to do analysis of the wind behavior to be used as a resource for wind farms as an unconventional power generating source, so that this power can contribute to the National Grid System (SIN) and meet the demand, at the same reducing the polluting emissions due to the use of fossil fuels as a mean of energy generation. Studies such as those of [2] highlight the statistical analysis using methods such as root test and equality of variance test to assess the wind persistence, so to determine the amount of wind necessary to achieve a good potential of power conversion for the Peninsula of Malaysia, this study was carried out from 2007 till 2009. [3] Poses a new mathematical model for the analysis of the auto correlation function applied to low wind speeds, achieving good estimates for the wind variations and pattern on the data studied by using the new expression for the analysis of the auto correlation function at different wind speed curves, and those outcomes match the outcomes found on the literature. [4] Underwent a study to analyze the methodologies employed to calculate the wind profiles, highlighting the downfalls of using low wind speed profiles for said analysis, presenting a compilation of data for a station located on the State of Zacatecas, Mexico, where the wind potential analysis was carried out at certain specific heights.

Due to the aforementioned the following study is carried out using the data base of the wind behavior log provided by the IDEAM for 18 weather stations located on the Departments of Atlántico, Bolívar, Cesar, Córdoba, La Guajira, Magdalena, Sucre, San Andrés y Providencia. Setting forth such statistical analysis of the wind potential at the stations as per the wind speed, direction, height and persistence.

Statistical Wind Analysis

Study Region

The Colombian Caribbean Region is located in the Northern side of Colombia and Northeast of South America. In this region we can find the Departments of Atlántico, Bolívar, Cesar, Córdoba, La Guajira, Magdalena, Sucre, and San Andrés y Providencia. As these are the departments that are the subject for the IDEAM study where the wind behavior was recorded for the stations from 2003 till 2013. Figure 1 and table 1 show the locations and names of the stations surveyed.

Table 1. Coordinates of the selected weather stations

Station	Department	Latitude	Length
Apto. Ernesto Cortissoz	Atlántico	10°53′54″N	74°46′54″W
Carmen de Bolívar	Bolívar	09°43′06″N	75°07′21″W
Sincerin	Bolívar	10°09′00″N	75°17′00″W
Nueva Florida	Bolívar	09°56′37″N	75°20′57″W
Santa Rosa de Simiti	Bolívar	07°57′23″N	73°56′46″W
Apto. Alfonso López	Cesar	10°26′06″N	74°14′58″W
Motilonia	Cesar	08°52'50"N	72°58'44"W
Turipaná	Córdoba	08°53′12″N	75°47′28″W
Apto. Los Garzones	Córdoba	08°49'25"N	75°49'33"W

UniCórdoba	Córdoba	08°47′16″N	75°51′28″W
Apto. Almirante Padilla	La Guajira	11°31′34″N	72°55′33″W
Puerto Bolívar	La Guajira	12°30'00"N	71°28'00"W
Apto. Simón Bolívar	Magdalena	11°07′10″N	74°13′50″W
Prado Sevilla	Magdalena	10°45′51″N	74°09′26″W
Primates	Sucre	09°31′00″N	75°21′00″W
UniSucre	Sucre	09°18′00″N	75°23′00″W
Apto. El Embrujo	San Andrés y Providencia	13°21′25″N	81°21′30″W
Apto. Sesquicentena	San Andrés y Providencia	12°35′01″N	81°42′40″W

Figure 1. Geographical location of the selected weather stations

Wind Speed and Persistence

To calculate the wind speed behavior it is necessary to do said analysis of such behavior as per the terrain where the measurements are located as well as the height, thus the Hellmann method is used for the prediction of the wind speed at different heights with the impact of the roughness of the surface where the survey is performed, and the auto correlation function for calculating the wind persistence according to its speed and study duration. Up next equations (1, 4)are presented for the Hellmann Method and the statements for achieving the auto correlation function[5-8].

$$\frac{v}{v_0} = \left(\frac{H}{H_0}\right)^{\alpha} \quad (1)$$

$$R_j = \frac{\sum_{i=1}^{n-j}(v_i - \bar{v})(v_{i+j} - \bar{v})}{\sum_{i=1}^{n}(v_i - \bar{v})^2} \quad (2)$$

$$F_{ACF} = \frac{1}{2}R_j(X_0 - 1) \quad (3)$$

$$F_{ACF} = \frac{1}{2}R_j(X_m - 1) \quad (4)$$

Where v is the wind speed, H is the height to be estimated. v_0 and H_0 are the benchmark values for the wind speed and the starting height. The roughness of the terrain corresponds to variable α . R_j is the auto correlation coefficient, *n* is the number data entries, X is the delay figure, $\bar{v}$ is the mean wind speed, resulting on F_{ACF} which is the auto correlation value that allows to estimate the wind persistence. The X_m and X_0 values pertain to the first minimum of the function curvature and the first intersection where the function goes through zero [8-12], respectively, as it is portrayed on figure 2 for the Motilonia and Nueva Florida Stations.

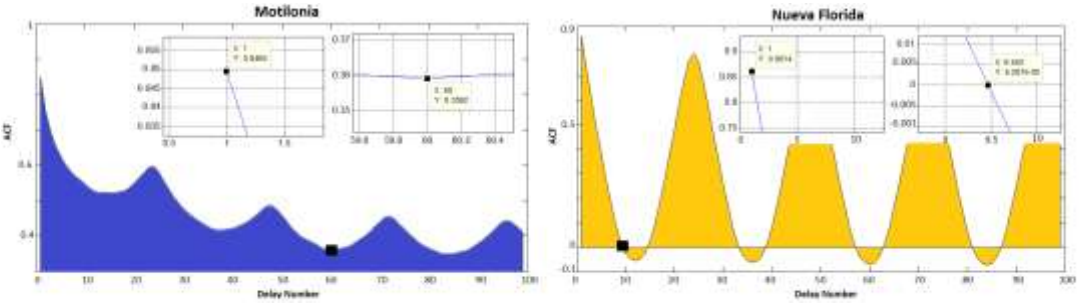

Figure 2. Auto correlation function

Results and Discussion

Wind Speed Analysis Timeline

With the data provided by the IDEAM a statistical analysis was carried out around the wind behavior across time starting in 2003 till 2013, upon which the wind speed values were obtained for each one of the stations, also an analysis of the wind estimate for each height on each station, wind direction analysis for each station and wind persistence analysis for each station as well.

Figure 3 shows the behavior of the annual wind speed for the set of 18 stations, attaining the wind speed values on intervals of 0.5 m/s up to 7.5 m/s. The Puerto Bolívar station being the highest of all values of wind speed.

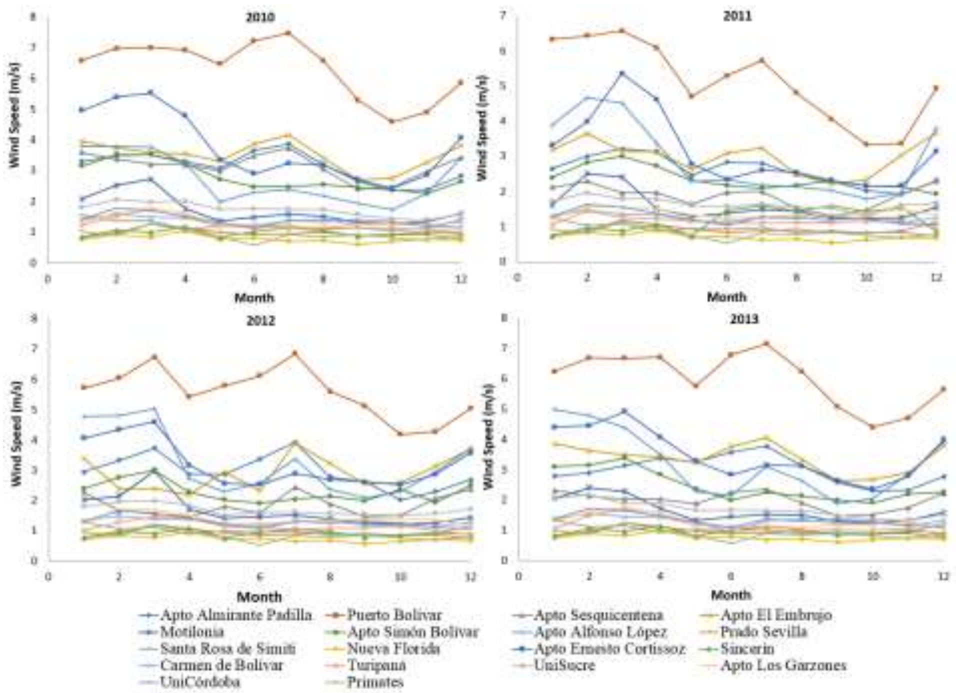

Figure 3. Mean wind speed in monthly periods

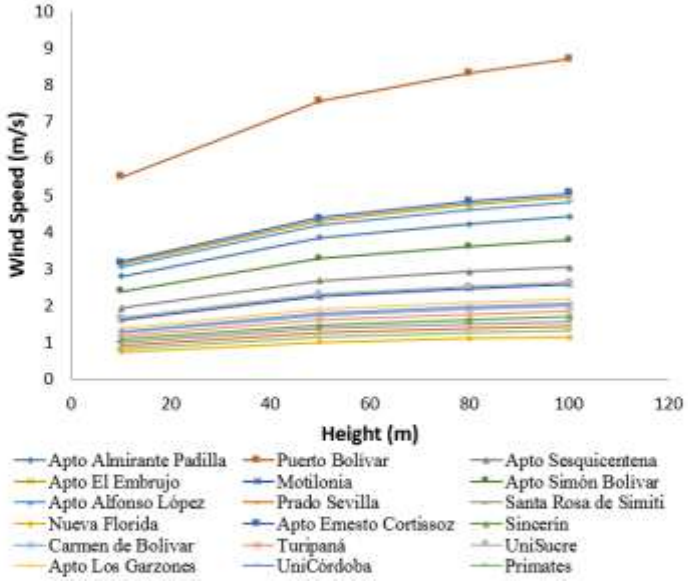

Figure 4. Average wind speed at different heights

By using the Hellmann Method presented on equation 1 the corresponding value of wind speed is estimated at different heights. Figure 4 shows the estimated values of wind speed for all 18 stations surveyed at a reference height of 10 m up to 100 m.

It is shown by the outcomes obtained that for this group of stations no significant differences arise in terms of the wind speed values as the height increases, as it is for the PuertoBolívar station that yields ranges of 5,5 m/s up to 9 m/s.

A monthly average wind speed analysis was performed during 2003 and 2013 yielding an outcome that shows the wind behavior on each month of the year, figure 5 shows that for months 5 to 9 a reduction of the wind takes place and for months 9 to 1 the wind increases, hence for the months 1 to 5 the trend is that the wind remains at an average speed.

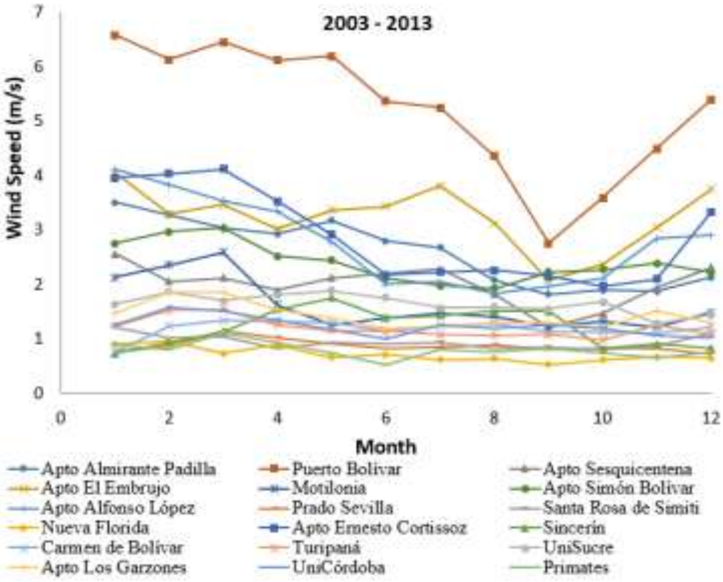

Figure 5. Monthly average wind speed

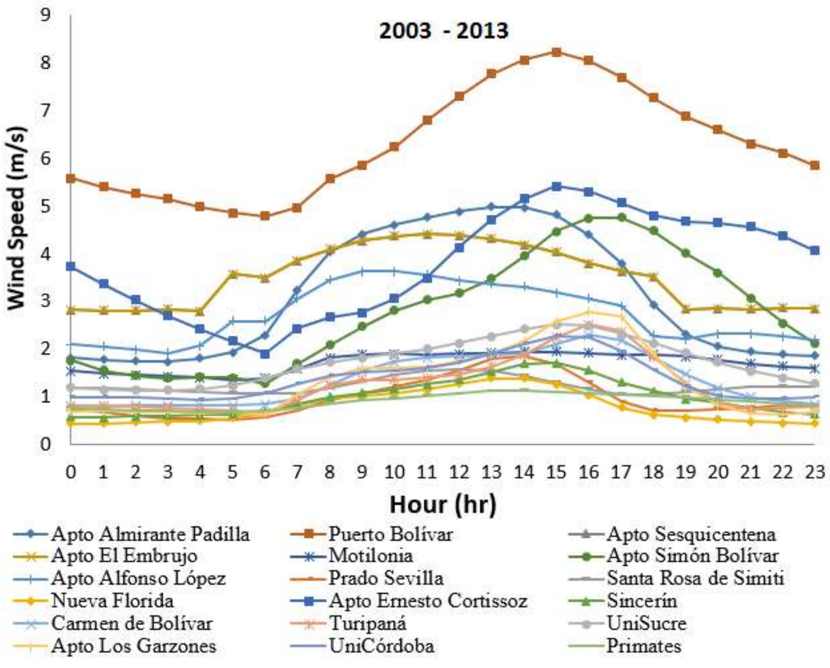

Figure 6. Hourly average wind speed

The wind speed values were obtained 24 hours per day starting on the year 2003 till 2013 as figure 6 shows. Which shows that for the 18 stations from 6:00 till 15:00 the wind speed increases to its maximum value and from 16:00 to 6:00 decreases to its minimum value, this is for most of the stations.

A wind direction study was conducted for all 18 stations, this is a keen variable for an efficientinstallation of an air generator so to take full advantage of the wind potential given its speed and direction. Figure 7 shows the wind roses for all 18 stations surveyed.

Table 2. Wind Persistence.

Station	r_1 (Y)	K_0 (X)	P_{ACF}
Apto Padilla	0.8524	8,096	3.02
Apto Alfonso Lopez	0.8861	13	5.32
Apto el Embrujo	0.8619	58.87	24.94
Apto Ernesto Cortissoz	0.8655	12	4.76
AptolosGarzones	0.7406	6.682	2.10
AptoSesquicentena	0.8619	58.87	24.94
AptoSimón Bolívar	0.8206	6.956	2.44
Carmen de Bolívar	0.8141	8.344	2.99
Motilonia	0.8495	60	25.06
Nueva Florida	0.8614	9.462	3.64
Prado Sevilla	0.8361	178	73.99
Puerto Bolívar	0.9068	12	4.99
Santa rosa de Simiti	0.8518	6	2.13
Sincerin	0.7822	10.52	3.72
Turipana	0.7595	8.1	2.70
UniCórdoba	0.8385	252	105.23
UniSucre	0.7978	9.213	3.28

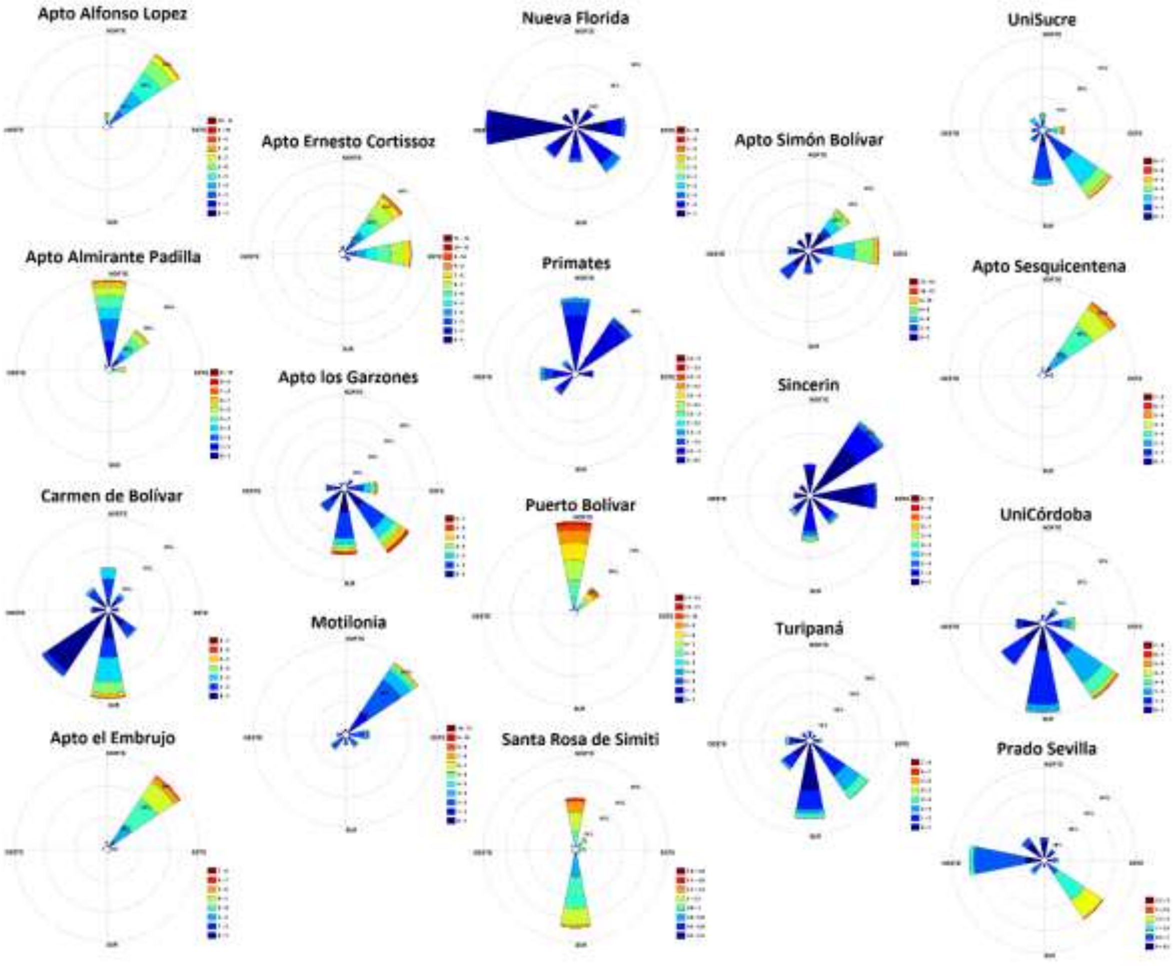

Figure 7. Wind Roses for the selected weather stations

The wind persistence analysis is conducted by solving equations (2,4) upon which the auto correlation functions are obtained as well as the delay values for each and every one of the 18 surveyed stations as table 2 shows. Which in turn points out that the stationsthat experienced the highest persistence of wind speed were UniCórdoba with an F_{ACF} value of 105.23, the Prado Sevilla Station with an F_{ACF} value of 73.99, the Motilona station with an F_{ACF} of 25.06, and the Apto Sesquicentena and Apto El Brujo stations both with an F_{ACF} value of 29.94.

Conclusions

The wind persistence analysis conducted for all 18 surveyed stations provided good outcomes regarding the sojourn of the wind speed at the stations, but this value is not conclusive in terms of the availability of wind potential, for instance at the Puerto Bolívar Station that yielded a higher wind speed with an average of 5, 49 m/s at the benchmark height, has a low auto correlation value located at 4.99. Which goes to show that this station does not yield the highest wind speed persistencecompared to the other station, but is does have the highest speed value with greater potential for power use.

The Apto. El Embrujo station located in the Department of Providencia yields the best wind persistence and average speed value for wind energy generation at an auto correlation function value of 24,94 and average wind speeds of 3.13 m/s at the benchmark height.

The usual allowed speeds to be considered for commissioning for an air generator go from 3 m/s as minimum wind speed to 25 m/s for maximum wind speed. Hence, the Apto Almirante Padilla, Puerto Bolívar, Apto Sesquicentena, Apto El Embrujo, Apto Simón Bolívar, Apto Alfonso López, Apto Ernesto Cortissoz yield a value of wind speed that provides a wind usable potential at an established height as it is shown on figure 4.

The set of stations that yielded wind speeds lower than 3 m/s, even so the wind persistence values were good, points out to the fact that a study can be conducted for the design of an air generator that can use this wind speeds for energy generation and therefore not missing the opportunity of unconventional energies.

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