# Wind Statistical Characterization in Mendoza Province. Argentina.

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*Abstract:* - In the following work, an analysis of the wind power of Mendoza Province is proposed, with the objective of its characterization and designing maps of average wind speeds. The data analyzed belongs to the wind and speed direction in the period from 1981 to 2020. The source of the information is the POWER project (Prediction Of Worldwide Energy Resources) open access database, from NASA (National Aeronautics and Space Administration). For data processing, descriptive statistical analysis was performed and the data were plotted by Kriging interpolation, which is based on the analysis of the geostatistical structure of variation of the variable to establish its behavior in space. As a result, a series of monthly maps were obtained plotting the average wind speeds for the Mendoza Province, thus characterizing the wind resource.

*Key-Words:* - wind, characterization, wind atlas, Mendoza, Argentina, wind power.

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## 1 Introduction

Wind, as a climatic element, is defined as “air in movement”. It is the result of airflow between areas with different air pressures, which are heated due to the incidence of solar radiation. Wind is an important resource in the generation of electric energy from renewable sources, [1].

Energy is a relevant factor for the growth and development of countries. In Argentina, due to the law 2619/15 and its modifications National Promotion Regime for the Use of Renewable Energy Sources for Electricity Production Law, [2], it prompts the use and incorporation of different sources of renewable energy sources to the national energy matrix. It is foreseen that up to the year 2025, 20 % of the electrical supply of the country will gradually come from non-conventional energies. Only 13% of renewable sources were produced in 2021, [2].

Wind power represents 74.1 % of the country's total renewable energy generation, [2] and 9.74 % of the total energy matrix in Argentina. Nowadays, Argentina holds approximately 950 installed wind turbines which, using the kinetic energy of the wind, produce electrical energy, [3]. Up to now, Mendoza does not produce electrical energy from wind energy; the project of the wind farm “El Sosneado” was approved in 2018, but it hasn’t started its building yet, [4].

To conduct a pre-feasibility study, it is necessary to know the wind resource, using a full statistical analysis, since the average speed only provides a convenience indicator at the measuring site. The specific location, having irregular high and low winds, can have the same average speed as another location with a constant average speed over an entire year, [5].

According to climatic conditions, the Mendocinian plains of the northern oasis show a great number of calm days; on the other hand, *La Payunia and the mountain depict a higher intensity and regularity of winds,* [6].

A statistical analysis is proposed of the information available for the province of Mendoza (Figure 1), from the NASA open access database, generated through the POWER (Prediction Of Worldwide Energy Resources) project, which is based on the Modern Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2). The information is generated through satellite systems that provide important data for climate studies and climatic processes, [7].

The new computer tools related to the processing of satellite images by remote sensing and the analysis of different layers of cartographic information using Geographic Information Systems, together with statistical interpolation techniques (geostatistics), make it feasible to reduce human error in the digital generation of maps, [8].

Fig. 1: political map of the Province of Mendoza, with its departments, [9]

# 2 Materials and Methods

The data used originate in the POWER project (NASA open access database), supplied in a global grid with a spatial resolution of 0.5 ° latitude by 0.5° longitude in different periods; monthly averages are chosen to work in the period 1981-2020 for the province of Mendoza.

## 2.1 Wind Direction

The direction from which the wind originates is measured clockwise from North, and in the database are expressed, [7], which were converted into sexagesimal degrees. The data is available to heights between 10 to 50 m above the earth's surface.

## 2.2 Wind Speed

The database provides the wind speed at various heights above the Earth's surface (10m and 50m) for the last 40 years (1981-2020). The validation of the meteorological parameters of MERRA-2 is based on comparisons of the main parameter with surface observations of the corresponding parameters, generally between 55% and 95% accuracy, [7].

## 2.3 Descriptive Statistics

Descriptive statistics on the available data were performed. Data not belonging to the geographic territory of the Province of Mendoza were cleared. The data review was automatic and the data ranges, minimum and maximum values were checked manually to find outliers, inconsistent data, and duplicates.

The average monthly data was collected between the period 1981-2020 for each geographical coordinate of Mendoza, the study did not consider the episodes of local winds called zonda which occur in 90% of the cases between May and November, and are characterized by being hot and dry winds of high speed between 10 and 33.3 m/s (36 and 120 km/h) depending on weather conditions and its frequency is from 7 to 9 episodes per year. Zonda has a very low frequency of occurrence in the summer, [10].

For data processing, descriptive statistical analysis was performed with the Infostat® software.

## 2.4 Data Mapping

To plot maps Kriging interpolation with Surfer 13 v7® software was used, which is based on the analysis of the geostatistical structure of variation of the variable to establish its behavior in space.

The Kriging method is a spatial inference method, which allows the estimation of a variable’s value in unsampled locations using the information provided by the sample, [11] [12].

# 3 Results

## 3.1 Wind Direction

The predominant wind direction is from the West and Southwest for 10 and 50 meters. To a minor extent, winds blow from the northeast (Table 1, Table 2, Table 3 and Table 4).

Table 1. Descriptive statistics of prevailing wind directions at 10 meters height, from January to June (1981-2020)

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Average | 154° 41' 20" | 144° 01' 41" | 153° 21' 42" | 190° 04' 37" | 196° 15' 51" | 210° 00' 38" |
| Minimum | 4° 45' 36" | 10° 21' 00" | 4° 22' 48" | 18° 58' 12" | 7° 41' 24" | 8° 56' 24" |
| Maximum | 332° 16' 48" | 340° 01' 48" | 350° 05' 24" | 348° 50' 24" | 356° 30' 00" | 352° 07' 12" |
| Medium | 125° 40' 12" | 109° 01' 12" | 114° 59' 42" | 186° 20' 42" | 203° 52' 30" | 244° 44' 42" |
| Mode | 95° 56' 24" | 116° 23' 24" | 114° 58' 12" | 305° 07' 12" | 275° 43' 12" | 240° 21' 36" |
| First quartile | 89° 59' 33" | 78° 59' 42" | 82° 45' 36" | 105° 51' 27" | 105° 37' 03" | 127° 00' 27" |
| Third quartile | 218° 01' 39" | 200° 30' 09" | 240° 18' 09" | 281° 28' 57" | 287° 52' 48" | 290° 33' 00" |

Table 2. Descriptive statistics of prevailing wind directions at 10 meters height from July to December (1981-2020)

| | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Average | 210° 37' 59" | 209° 30' 59" | 198° 41' 03" | 196° 12' 40" | 185° 33' 11" | 174° 57' 20" |
| Minimum | 12° 47' 24" | 15° 03' 36" | 13° 23' 24" | 20° 13' 48" | 24° 44' 24" | 25° 25' 48" |
| Maximum | 351° 26' 24" | 341° 56' 24" | 349° 01' 12" | 347° 41' 24" | 351° 18' 36" | 334° 18' 36" |
| Medium | 245° 21' 18" | 246° 50' 24" | 197° 53' 06" | 182° 58' 12" | 165° 49' 30" | 153° 53' 06" |
| Mode | 305° 09' 36" | 105° 07' 12" | 292° 18' 36" | 105° 00' 00" | 102° 01' 48" | 112° 52' 48" |
| First quartile | 122° 41' 51" | 121° 38' 15" | 115° 28' 03" | 119° 13' 39" | 111° 45' 00" | 106° 04' 30" |
| Third quartile | 293° 50' 33" | 294° 16' 57" | 287° 42' 54" | 282° 08' 33" | 270° 09' 36" | 255° 21' 54" |

Table 3. Descriptive statistics of prevailing wind directions at 50 meters height, from January to June (1981-2020)

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Average | 163° 35' 42" | 154° 11' 24" | 166° 07' 14" | 193° 29' 40" | 199° 45' 22" | 214° 03' 51" |
| Minimum | 19° 28' 12" | 5° 34' 12" | 7° 02' 24" | 3° 00' 00" | 9° 30' 00" | 12° 04' 12" |
| Maximum | 334° 09' 36" | 354° 09' 36" | 352° 48' 36" | 345° 34' 48" | 352° 31' 48" | 352° 03' 36" |
| Medium | 140° 04' 30" | 115° 08' 24" | 129° 08' 24" | 198° 13' 12" | 219° 11' 42" | 249° 18' 00" |
| Mode | 68° 03' 36" | 65° 15' 00" | 53° 11' 24" | 97° 09' 36" | 303° 07' 12" | 305° 59' 24" |
| First quartile | 92° 26' 06" | 80° 15' 18" | 84° 44' 06" | 106° 07' 03" | 107° 04' 48" | 132° 29' 15" |
| Third quartile | 245° 12' 18" | 241° 30' 00" | 260° 09' 18" | 284° 03' 00" | 292° 06' 09" | 292° 43' 21" |

Table 4. Descriptive statistics of prevailing wind directions at 50 meters height, from July to December (1981-2020)

| | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Average | 213° 28' 34" | 212° 35' 26" | 201° 23' 09" | 200° 33' 27" | 193° 12' 14" | 183° 31' 27" |
| Minimum | 7° 16' 48" | 10° 30' 00" | 11° 43' 12" | 19° 09' 36" | 21° 27' 36" | 17° 15' 00" |
| Maximum | 343° 09' 36" | 340° 09' 36" | 347° 04' 48" | 353° 37' 12" | 341° 18' 36" | 338° 41' 24" |
| Medium | 248° 27' 18" | 249° 03' 54" | 211° 30' 36" | 202° 17' 24" | 185° 21' 00" | 169° 34' 30" |
| Mode | 301° 03' 36" | 299° 48' 36" | 303° 05' 24" | 127° 04' 48" | 112° 48' 36" | 287° 50' 24" |
| First quartile | 127° 09' 09" | 123° 34' 30" | 114° 43' 30" | 119° 46' 21" | 112° 48' 36" | 107° 09' 09" |
| Third quartile | 295° 11' 06" | 295° 44' 24" | 289° 28' 57" | 283° 58' 48" | 277° 07' 39" | 267° 34' 57" |

Table 5. Descriptive statistics of prevailing wind speeds (m/s) for 10 meters height, from January to June (1981-2020)

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Average | 4,19 | 4,08 | 3,93 | 3,78 | 3,75 | 3,94 |
| Minimum | 2,55 | 2,52 | 2,43 | 2,40 | 2,17 | 2,28 |
| Maximum | 6,28 | 5,97 | 5,91 | 5,46 | 7,61 | 7,41 |
| Medium | 4,32 | 4,21 | 4,01 | 3,80 | 3,63 | 3,74 |
| Mode | 4,38 | 4,27 | 4,09 | 3,59 | 3,48 | 3,52 |
| First quartile | 3,76 | 3,60 | 3,56 | 3,45 | 3,33 | 3,39 |
| Third quartile | 4,63 | 4,52 | 4,35 | 4,14 | 4,05 | 4,39 |
| Standard deviation | 0,656 | 0,644 | 0,608 | 0,529 | 0,700 | 0,768 |
| Coefficient of variation | 15,64% | 15,78% | 15,44% | 13,99% | 18,68% | 19,49% |

Table 6. Descriptive statistics of prevailing wind speeds (m/s) for 10 meters height, from July to December (1981-2020)

| | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Average | 4,04 | 4,27 | 4,36 | 4,56 | 4,53 | 4,46 |
| Minimum | 2,45 | 2,59 | 2,59 | 2,64 | 2,62 | 2,52 |
| Maximum | 7,10 | 6,75 | 6,00 | 7,17 | 7,08 | 7,04 |
| Medium | 3,93 | 4,23 | 4,39 | 4,60 | 4,61 | 4,55 |
| Mode | 3,68 | 3,99 | 4,36 | 4,91 | 4,60 | 4,68 |
| First quartile | 3,58 | 3,85 | 3,99 | 4,16 | 4,11 | 4,04 |
| Third quartile | 4,39 | 4,64 | 4,77 | 4,99 | 4,99 | 4,91 |
| Standard deviation | 0,670 | 0,620 | 0,602 | 0,680 | 0,714 | 0,722 |
| Coefficient of variation | 16,61% | 14,53% | 13,79% | 14,91% | 15,78% | 16,19% |

Table 7. Descriptive statistics of prevailing wind speeds (m/s) for 50 meters height, from January to June (1981-2020)

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Average | 5,30 | 5,23 | 5,17 | 5,15 | 5,25 | 5,58 |
| Minimum | 2,68 | 2,46 | 2,38 | 2,43 | 2,35 | 2,82 |
| Maximum | 8,05 | 7,94 | 7,97 | 7,8 | 9,76 | 9,45 |
| Medium | 5,62 | 5,52 | 5,46 | 5,38 | 5,29 | 5,48 |
| Mode | 6,30 | 6,21 | 5,74 | 5,3 | 5,38 | 5,02 |
| First quartile | 4,59 | 4,46 | 4,46 | 4,52 | 4,63 | 4,94 |
| Third quartile | 6,16 | 6,12 | 6,04 | 5,90 | 5,87 | 6,22 |
| Standard deviation | 1,168 | 1,172 | 1,149 | 1,002 | 1,073 | 1,028 |
| Coefficient of variation | 22,06% | 22,41% | 22,19% | 19,45% | 20,39% | 18,40% |

Table 8. Descriptive statistics of prevailing wind speeds (m/s) for 50 meters height from July to December (1981-2020**)**

| | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Average | 5,67 | 5,88 | 5,81 | 5,92 | 5,77 | 5,61 |
| Minimum | 2,71 | 3 | 2,79 | 2,78 | 2,7 | 2,62 |
| Maximum | 9,04 | 8,71 | 8,08 | 8,96 | 8,71 | 8,75 |
| Medium | 5,68 | 5,98 | 6,02 | 6,125 | 6,01 | 5,92 |
| Mode | 6,06 | 6,25 | 6,33 | 6,38 | 6,62 | 6,24 |
| First quartile | 5,08 | 5,29 | 5,16 | 5,23 | 5,09 | 4,98 |
| Third quartile | 6,29 | 6,58 | 6,61 | 6,73 | 6,64 | 6,46 |
| Standard deviation | 0,987 | 0,992 | 1,056 | 1,130 | 1,189 | 1,204 |
| Coefficient of variation | 17,37% | 16,86% | 18,15% | 19,06% | 20,58% | 21,42% |

Wind speed is variable, average annual wind speed at 10 meters above sea level is 4.2 m/s among a range of 2.17 m/s and 7.61 m/s (Table 5 and Table 6).

Regarding cases of 50-meter heights, the average value is 5.5 m/s in a range of 5.15 and 5.92 m/s (Table 7 and Table 8). Among the data analyzed, there is no high relative dispersion between the datasets.

Results were plotted through Kriging's interpolation for each month, based on the average data of each geographic coordinate of Mendoza province. From January to April, the average wind speeds range between 2.43 m/s and 8 m/s, classified between light

and fresh breezes according to the Beaufort scale (Figure 2).

Between May and August, the average wind speed is between 2.35 m/s and 9.04 m/s, which is classified as light breeze and fresh breeze, which coincides with mid Autumn and the beginning of Winter (Figure 3).

Between September and December, the average wind speeds are between 2.62 m/s and 8.96 m/s, which is classified as light breeze and fresh breeze on the Beaufort scale (Figure 4).

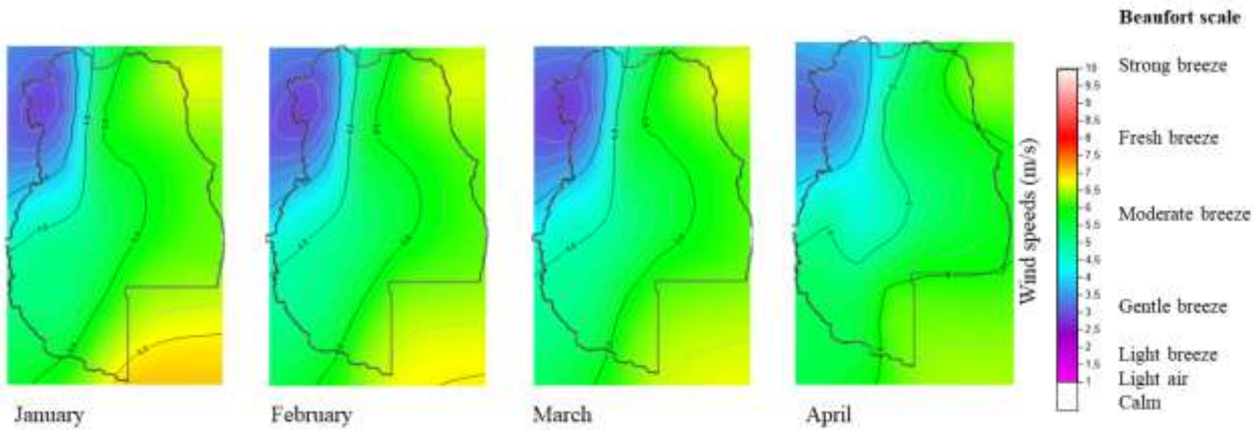


Fig 2: maps of average wind speeds for Mendoza Province from January to April. The period analyzed 1981-2020. Height 50 meters

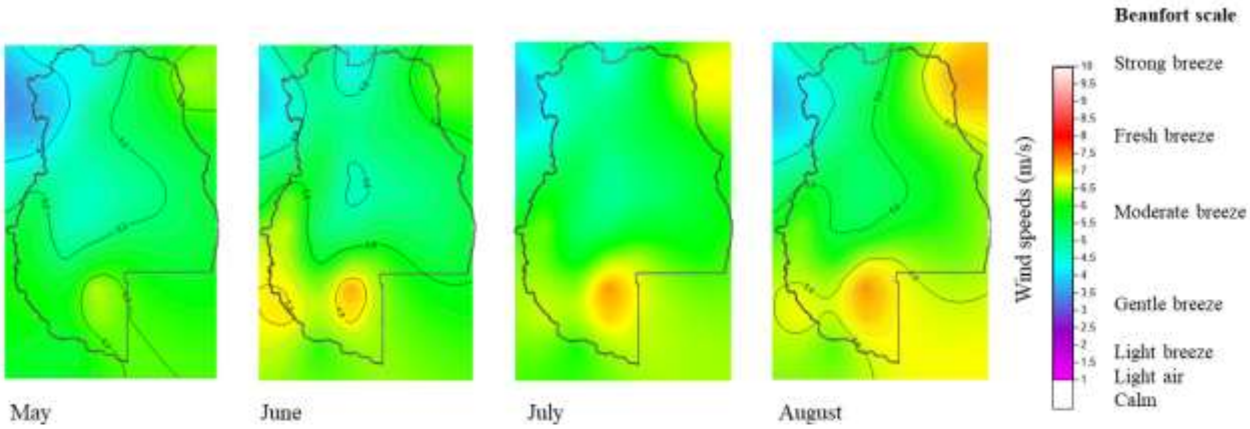


Fig. 3: Maps of average wind speeds for the Province of Mendoza from May to August. The period analyzed 1981-2020. Height 50 meters

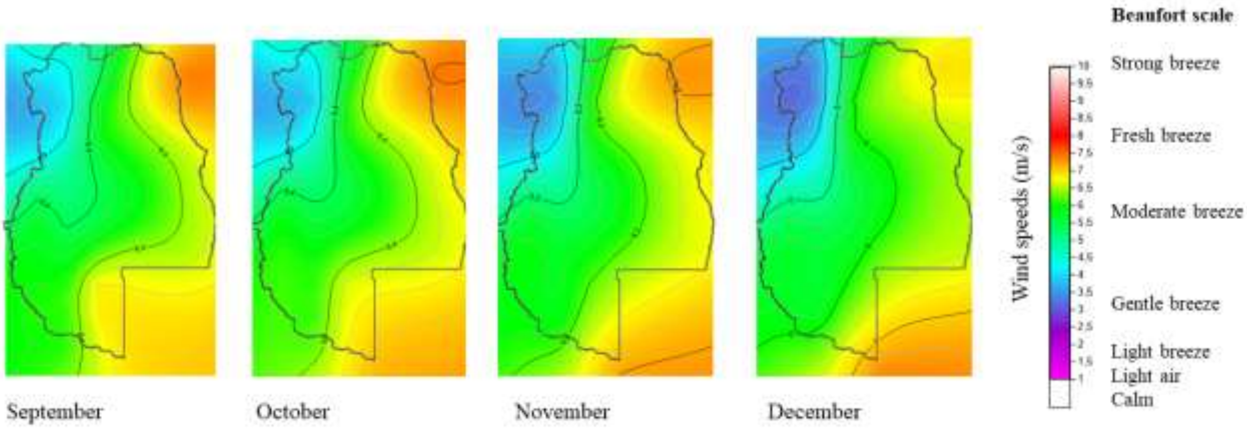


Fig. 4: maps of average wind speeds for Mendoza Province from September to December. The period analyzed 1981-2020 Height 50 meters

## 4 Conclusion

Results obtained allow us to characterize Mendoza's winds based on historical data over a range of 40 years. The data variability in that period is low. It can be highlighted that the Northeast area is the most adequate for the development of wind power projects, in the departments of Las Heras, Luján de Cuyo, and Tupungato. Towards the south, in the Departments of General Alvear, San Rafael y Malargüe, results agree with the work of [6] and [13].

Deeper studies regarding speed and consistency studies are required for electric power. Not only speed but also frequency of wind direction through time are important factors to identify orientation and optimize wind turbine distribution inside an eolic farm; however, other factors influence the implementation of wind farms: energy needs and potential, urban centers and nearby populations, medium and high voltage grids to join the Argentine Interconnected System. This study is the beginning of many more to be carried out to develop the wind potential in Mendoza´s province.

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**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

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**Conflict of Interest**

The authors have no conflicts of interest to declare.