HOLOS
ISSN 1807 - 1600

REGIONAL WIND VARIABILITY IN THE STATE OF RIO GRANDE DO SUL, BRAZIL

S. D. SANTOS[1], I. S. LEONARDI[2], M. D. CASSENOTE[3], A. M. SILVA[4], E. J. SEIDEL[5]
Universidade Federal de Santa Maria
ORCID ID: https://orcid.org/0000-0002-9656-0699*
enioseidel@gmail.com*

Submitted 31/08/2023 - Accepted 23/09/2025

DOI: 10pts.15628/holos.2025.15955

ABSTRACT

Understanding the spatial and temporal dynamics of the wind is fundamental for human activities. The objective of this work is to carry out a regional and temporal comparison of the direction (degrees), speed (m.s^{-1}) and gusts (m.s^{-1}) of the wind in the territory of the state of Rio Grande do Sul, Brazil. Data from 44 automatic meteorological stations in the years 2020 and 2021 were considered. The different mesoregions of the state of Rio Grande do Sul (RS) and the different seasons of the year (spring, summer, autumn and winter) were compared using circular and non-parametric statistical methods. Finally, spatial interpolation maps of wind direction, speed and gusts were generated. It is noticed that there is a predominance of winds in the east and east-southeast directions, being concentrated winds and with little directional variability. In addition, the winds have both higher average speeds and higher average gusts in the southern region and on the coast of the state of Rio Grande do Sul. The lowest speeds and smallest gusts are observed in the North/Northwest of the state of Rio Grande do Sul.

KEYWORDS: Wind direction, Wind speed, Regional climatology, Circular statistics, Spatial interpolation.

VARIABILIDADE REGIONAL DO VENTO NO ESTADO DO RIO GRANDE DO SUL, BRASIL

RESUMO

Compreender a dinâmica espacial e temporal do vento é fundamental para as atividades humanas. O objetivo deste trabalho é realizar uma comparação regional e temporal da direção (graus), velocidade (m.s^{-1}) e rajadas (m.s^{-1}) do vento no território do estado do Rio Grande do Sul, Brasil. Foram considerados dados de 44 estações meteorológicas automáticas nos anos de 2020 e 2021. Comparações entre as diferentes mesorregiões do estado do Rio Grande do Sul (RS) e as distintas estações do ano (primavera, verão, outono e inverno) foram realizadas por meio de métodos de estatística circular e estatística não-paramétrica. Por fim, foram gerados mapas de interpolação espacial da direção, velocidade e rajadas do vento. Percebe-se que há um predomínio de ventos nas direções leste e leste-sudeste, sendo ventos concentrados e com pouca variabilidade direcional. Além disso, os ventos apresentam maiores velocidades médias e maiores rajadas médias na região Sul e no litoral do estado do Rio Grande do Sul. Já as menores velocidades e menores rajadas são observadas no Norte/Noroeste do estado do Rio Grande do Sul.

Palavras chave: Direção do vento, Velocidade do vento, Climatologia regional, Estatística circular, Interpolação espacial.

1 INTRODUCTION

A geographic region depends on the climatic dynamics exerted by rainfall, temperature, radiation, winds, among others. Regarding the wind, the behavior in terms of direction and speed are of theoretical and practical interest. These wind characteristics are investigated in terms of predominant direction, average speed, variations in temporal and spatial behavior, among others. According to Pontes et al. (2018), the intensity and direction of winds are determined by the spatial and temporal variation of the energy balance at the earth's surface, causing variations in the atmospheric pressure field.

Wind is one of the main elements in the characterization of the regional climate, as it is strongly associated with socioeconomic and material damage to the geographic space (Wollmann & Galvani, 2012). In addition, wind is critical for monitoring and forecasting weather patterns and global climate (Ponciano & Back, 2022).

In the field of research, for example, the agro-environmental sciences use renewable energy from wind in the production of wind energy (Munhoz & Garcia, 2008; Alves & Silva, 2011). In agriculture, wind speed and direction are considered when applying pesticides, pollination, disease propagation and windbreak practices (Munhoz & Garcia, 2008; Alves & Silva, 2011). Also, in civil construction, ventilation is an ally of thermal comfort in buildings in regions with hot and humid climates and wind speed is impacted by different constructive arrangements (Lima & Bittencourt, 2017). The study of wind loads is also essential for the structural safety of buildings (Almeida et al. 2021).

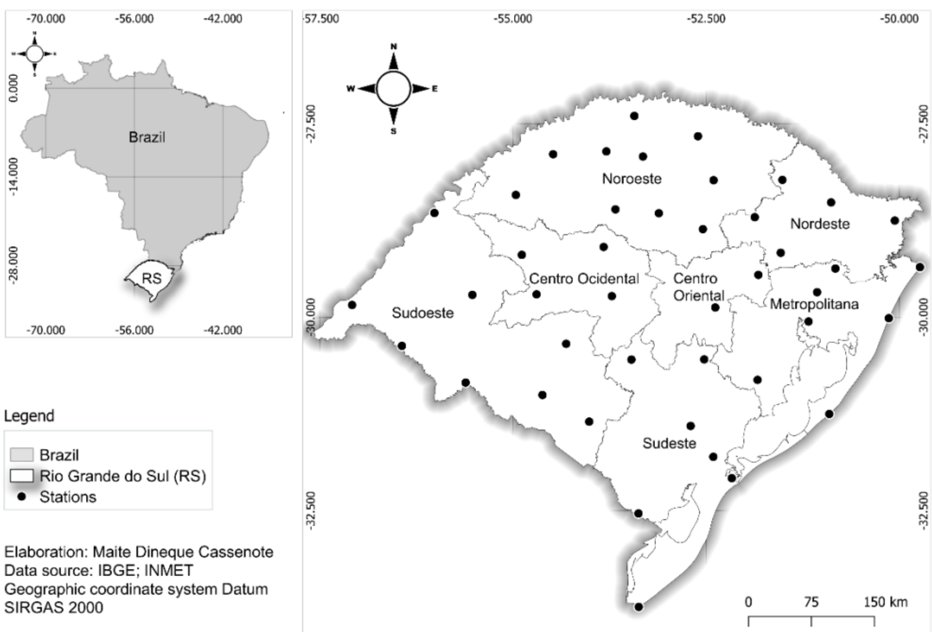
The literature presents several studies on wind dynamics in various regions of Brazil, with research in areas of the North (Pontes et al., 2018), Northeast (Borges et al., 2018; Araújo Junior et al., 2019; Silva & Barbosa, 2022), Central-West (Silva & Vieira, 2016), Southeast (Sobral et al., 2018; Ramos et al., 2021) and South (Castelhano & Rosiguini, 2018; Wahrlich et al., 2018; Terassi et al., 2019; Ponciano & Back, 2022). With regard specifically to studies on the behavior of the wind in the state of Rio Grande do Sul (RS), it is possible to highlight the research by Favera et al. (2012), who studied the behavior of winds in the central region of the state of Rio Grande do Sul, by Rockett et al. (2017), who evaluated the space-time dynamics of winds in the extreme north of the Coastal Plain of Rio Grande do Sul, and Barbara Neto et al. (2021), who evaluated wind speed and direction in the coastal watershed of the state of Rio Grande do Sul.

The local wind regime is described based on historical series of horizontal velocity and direction data (Borges et al., 2018). Wind speed is a vector quantity defined by its intensity, direction and direction, and the direction and direction can be expressed in angle or by position in relation to the cardinal points according to the wind rose (Back, 2020). Velocity and gusts, measured in meters per second (m.s-1), are continuous quantitative variables that can be studied under the prism of statistical inference. Wind direction, measured in degrees, is a circular variable that requires a specific approach through circular statistics. In circular statistics (Fisher, 1993; Pewsey et al., 2013) a circular observation can be ascertained on a circle of unit radius or unit vector in the plane and if the direction is defined, then each circular observation is given in angular form.

There are few studies that describe the behavior of winds in the State of Rio Grande do Sul (RS). In addition, there is no assessment approach for wind characteristics considering the mesoregions of the state of RS and the effects of the seasons. Thus, the objective of this work is to carry out a regional and temporal comparison of the direction (in degrees), speed (in $m.s^{-1}$) and gusts (in $m.s^{-1}$) of the wind in the territory of the state of Rio Grande do Sul, Brazil.

2 MATERIAL AND METHODS

Wind direction (in degrees), speed and gusts (in $m.s^{-1}$) data were collected from the Instituto Nacional de Meteorologia (INMET) website [https://portal.inmet.gov.br/], using information from the 44 automatic meteorological stations in the state of Rio Grande do Sul (RS) (Figure 1). The years 2020 and 2021 were considered for analysis. The hourly data were arranged for each meteorological station across every month of the year. Finally, the average of the hourly data generated the representative value of the month for direction (degrees), speed ($m.s^{-1}$) and gusts ($m.s^{-1}$) of the wind.



Source: Own elaboration. *Image created in the QGIS, using data from IBGE and INMET.

Figure 1: Location of the 44 automatic meteorological stations in the mesoregions of the state of Rio Grande do Sul, Brazil.

Sixteen wind directions were used, equally spaced every 22.5 degrees, in accordance with the World Meteorological Organization (WMO, 2008) meteorological convention. The directions and their corresponding intervals were: north N (348.75 – 11.25), north-northeast NNE (11.25 – 33.75), northeast NE (33.75 – 56.25), east-northeast ENE (56.25 – 78.75), east E (78.75 – 101.25), east-southeast ESE (101.25 – 123.75), southeast SE (123.75 – 146.25), south-southeast SSE (146.25 – 168.75), south S (168.75 – 191.25), south-southwest SSW (191.25 – 213.75), southwest SW (213.75 – 236.25), west-southwest WSW (236.25 – 258.75), west W (258.75 – 281.25), west-northwest WNW (281.25 – 303 .75), northwest NW (303.75 – 326.25) and north-northwest NNW (326.25 – 348.75).

To assess the effect of mesoregions on wind characteristics, meteorological stations covering the mesoregions of RS were considered (Figure 1). The mesoregions considered were: Centro Rio-Grandense, Metropolitana de Porto Alegre, Nordeste Rio-Grandense, Noroeste Rio-Grandense, Sudeste Rio-Grandense and Sudoeste Rio-Grandense. The Centro Rio-Grandense mesorregion was considered as the union of the Centro Ocidental Rio-Grandense and Centro Oriental Rio-Grandense mesoregions.

As for the evaluation of the seasonal (temporal) effect of wind characteristics in RS, the months of the year were grouped into seasons as follows: summer (months of January, February and March), autumn (months of April, May and June), winter (months of July, August and September) and spring (months of October, November and December).

First, a descriptive analysis of the wind characteristics was carried out. The description of the wind direction (degrees) was performed by means of circular mean, circular median, circular standard deviation, circular concentration coefficient and application of the uniformity test. In order to characterize the wind speed ($m.s^{-1}$) and the gusts ($m.s^{-1}$), mean, median, standard deviation, asymmetry coefficient were calculated and the Shapiro-Wilk normality test was applied.

To compare the behavior of wind characteristics in different mesoregions and seasons, hypothesis tests were applied. For all tests, a probability of 5% was considered.

In comparing the behavior of the direction (degrees) of the wind among the six mesoregions and among the four seasons of the year, the Watson-Wheeler test was applied. For post-hoc comparisons, the Watson-Wheeler 2 to 2 test was applied, with Bonferroni correction.

For the comparison of wind speed ($m.s^{-1}$) and gust ($m.s^{-1}$) among the six mesoregions and among the four seasons of the year, the Kruskall-Wallis test was applied. For post-hoc comparisons, Dunn's test was applied, with Bonferroni correction.

For spatial interpolation of wind direction (in cardinal points format) the method of k nearest neighbors (kNN) was used. For spatial interpolation of wind speed ($m.s^{-1}$) and gusts ($m.s^{-1}$), the inverse square of distance (IQD) method was used.

Statistical analyzes were performed in the R program (R CORE TEAM, 2021). The circular package (AGOSTINELLI; LUND, 2022) was used for the circular descriptive analysis and the Watson-Wheeler test. The packages base, moments (KOMSTA; NOVOMESTKY, 2015) and stats were used for the descriptive analysis of the data and the Shapiro-Wilk test. The agricolae package (MENDIBURU, 2021) to perform the Kruskall-Wallis test. The dunn.test package (DINNO, 2017) was used to perform Dunn's test. The kknn package (SCHLIEP; HECHENBICHLER, 2016) was used to do the interpolation via the kNN method. The gstat package (PEBESMA, 2004) was used to perform the interpolation via IQD.

3 RESULTS AND DISCUSSION

Table 1 shows the behavior of wind characteristics according to the mesoregions, in 2020 and 2021, respectively. It is observed that, in 2020, all mesoregions have average winds between the east-northeast (ENE), east (E) and east-southeast (ESE) directions (56.25 to 123.75 degrees), with the exception of the Nordeste Rio-Grandense mesoregion that has an average northeast (NE) direction (51.08 degrees). In 2021, all mesoregions have average winds between east (E) and east-southeast (ESE) directions (67.50 to 123.75 degrees), with the exception of the Nordeste Rio-Grandense mesoregion, which has an average northeast (NE) direction (56.19 degrees).

Santos et al. (2019), when studying the directional behavior of the wind for the years 2017 and 2018, identified predominant winds in the east (E), east-southeast (ESE) and east-northeast (ENE) directions in the state of Rio Grande do Sul. Thus, it is clear that, over the years, there has been a trend of predominance of east-northeast (ENE) to east-southeast (ESE) winds in RS.

Rockett et al. (2017), observed predominant winds in the northeast (NE) and southwest (SW) directions in the extreme north of the coast of Rio Grande do Sul. In this study, however, the Metropolitana de Porto Alegre mesoregion, which includes the northern region of the coastal plain of the state of RS, presents predominant winds in the east-northeast (ENE) direction.

Favera et al. (2012), when evaluating winds in the central region of the state of RS, found more predominant winds in the southeast (SE) direction. This result is similar to that observed in this study, which showed average winds in the east-southeast (ESE) direction in the Centro Rio-Grandense mesoregion. Barbara Neto et al. (2021), observed a predominance of winds in the northeast (NE) direction in the southernmost region and on the coast of the state of RS. This result is close to that observed in this study with winds from east (E) to east-northeast (ENE) in the Sudeste Rio-Grandense and Metropolitana de Porto Alegre mesoregions, respectively.

In addition, in 2020, all mesoregions did not present uniformly distributed winds according to the uniformity test, with emphasis on the Centro Rio-Grandense, Noroeste Rio-Grandense and Sudoeste Rio-Grandense mesoregions, which, with concentration coefficients greater than 0.70, have well-concentrated winds in a preferred direction, which, on average, is defined as eastward (E) (Table 1). In 2021, all mesoregions did not show evenly distributed winds based on the uniformity test, with emphasis on the Centro Rio-Grandense and Sudoeste Rio-Grandense mesoregions which, with concentration coefficients greater than 0.70, have winds well concentrated in a preferred direction (mean east direction (E) and mean southeast direction (SE), respectively) (Table 1).

Table 1: Descriptive measures* for wind direction (degrees), speed ($m.s^{-1}$) and gusts ($m.s^{-1}$) for the mesoregions of the state of Rio Grande do Sul, Brazil, in 2020 and 2021.

Mesorregion	Mean	Direction	Standard Deviation	Concentration Coefficient	Uniformity Test
Direction of wind (degrees)					
2020					
Centro	102.89	ESE	0.78	0.74	No
Metropolitana	75.00	ENE	1.19	0.49	No
Nordeste	51.08	NE	1.12	0.53	No

Noroeste	90.94	E	0.66	0.80	No
Sudeste	87.21	E	1.11	0.54	No
Sudoeste	108.45	ESE	0.58	0.84	No
			2021		
Centro	107.41	ESE	0.54	0.86	No
Metropolitana	85.36	E	1.28	0.44	No
Nordeste	56.19	NE	0.98	0.62	No
Noroeste	108.37	ESE	1.11	0.54	No
Sudeste	97.22	E	1.19	0.49	No
Sudoeste	116.82	ESE	0.38	0.93	No
Mesorregion	Mean	Median	Standard Deviation	Coefficient of Asymmetry	Normality Test
			Speed of wind ($m.s^{-1}$)		
			2020		
Centro	2.33	2.22	0.46	0.59	No
Metropolitana	2.40	1.71	1.55	1.50	No
Nordeste	2.91	2.94	1.11	0.68	No
Noroeste	2.37	2.30	1.04	0.05	Yes
Sudeste	3.51	3.20	0.96	0.97	No
Sudoeste	2.64	2.67	0.94	-0.74	No
			2021		
Centro	2.33	2.20	0.61	1.16	No
Metropolitana	1.83	1.44	0.78	0.56	No
Nordeste	2.65	2.88	0.72	-1.29	No
Noroeste	2.12	2.14	1.27	-0.03	No
Sudeste	3.20	3.27	1.24	-0.45	No
Sudoeste	2.08	2.03	1.06	0.15	No
Mesorregion	Mean	Median	Standard Deviation	Coefficient of Asymmetry	Normality Test
			Gusts of wind ($m.s^{-1}$)		
			2020		
Centro	5.47	5.50	0.72	-0.11	Yes
Metropolitana	5.74	5.37	2.18	1.57	No
Nordeste	6.22	6.53	1.43	-0.32	No
Noroeste	5.65	5.61	1.18	-0.01	Yes
Sudeste	7.03	7.04	1.11	0.53	Yes
Sudoeste	5.89	6.04	1.05	-0.91	No
			2021		
Centro	5.42	5.32	0.89	0.43	Yes
Metropolitana	4.86	4.72	1.11	0.32	Yes
Nordeste	5.88	6.21	1.21	-1.30	No
Noroeste	5.15	5.28	1.68	-0.29	No
Sudeste	6.68	6.87	1.64	-0.64	No
Sudoeste	5.30	5.39	1.28	-0.17	Yes

*Circular descriptive measures for wind direction: Circular Mean, Circular Median, Circular Standard Deviation, and Circular Concentration Coefficient.

Source: Own elaboration.

In 2020 and 2021, the Sudeste Rio-Grandense mesoregion has the highest average wind speed with 3.51 $m.s^{-1}$ and 3.20 $m.s^{-1}$, respectively. In terms of variability, the Centro Rio-Grandense mesoregion shows less dispersion (standard deviation of 0.46 $m.s^{-1}$ in 2020 and 0.61 $m.s^{-1}$ in 2021) in wind speeds, indicating more homogeneity (Table 1).

Also, in Table 1 it is verified that in both years (2020 and 2021) the mesoregion that presents the highest average gusts is the Sudeste Rio-Grandense, with values equal to 7.03 $m.s^{-1}$ and 6.68 $m.s^{-1}$, respectively.

Barbara Neto et al. (2021), in their study, observed wind speeds of up to 6.1 $m.s^{-1}$ in the southernmost region and on the coast of the state of Rio Grande do Sul, which corroborates the results of this work in relation to wind gusts.

When the standard deviation in 2020 and 2021 is taken into account, the Centro Rio-Grandense mesoregion is the one with the lowest values, being 0.72 $m.s^{-1}$ and 0.89 $m.s^{-1}$, respectively, thus indicating a homogeneity of gusts from this mesoregion.

Table 2 presents the behavior of the wind characteristics according to the seasons, in 2020 and 2021, respectively. In 2020, the winds have an average east (E) direction in the summer and winter seasons, an average northeast (NE) direction in autumn and an average east-southeast (ESE) direction in spring. In 2021, the wind has a preferential east-southeast (ESE) average direction in spring and summer, and a preferential east (E) direction in autumn and winter seasons.

Furthermore, both in 2020 and in 2021, the winds are more concentrated in the spring and summer seasons, with concentration coefficients greater than or equal to 0.70 (Table 2). Santos et al. (2019) observed more concentrated winds in the months corresponding to the spring and summer seasons in all mesoregions, with the exception of the Nordeste Rio-Grandense mesoregion, which presented concentration coefficient values lower than 0.70 in all months.

Silva et al. (1997), in Pelotas, RS, observed winds in the east (E) direction in spring and summer, in the southeast (SE) direction in autumn, and in the northeast (NE) direction in the winter season.

Table 2: Descriptive measures* for wind direction (degrees), speed (m.s-1) and gusts (m.s-1) for the seasons of the year in the state of Rio Grande do Sul, Brazil, in 2020 and 2021.

Season	Mean	Direction	Standard Deviation	Concentration Coefficient	Uniformity Test
Direction of wind (degrees)					
2020					
Summer	93.32	E	0.45	0.90	No
Autumn	46.10	NE	1.44	0.35	No
Winter	85.11	E	0.87	0.68	No
Spring	112.75	ESE	0.60	0.83	No
2021					
Summer	108.02	ESE	0.84	0.70	No
Autumn	97.48	E	1.35	0.40	No
Winter	79.44	E	1.01	0.60	No

HOLOS
ISSN 1807 - 1600

Season	Mean	Median	Standard Deviation	Coefficient of Asymmetry	Normality Test
Spring	110.97	ESE	0.59	0.84	No

Season	Mean	Median	Standard Deviation	Coefficient of Asymmetry	Normality Test
Speed of wind ($m.s^{-1}$)					
2020					
Summer	2.78	2.63	1.27	0.97	Yes
Autumn	2.66	2.63	1.18	0.62	No
Winter	2.55	2.62	0.89	0.02	No
Spring	2.67	2.85	1.10	0.16	No
2021					
Summer	2.16	2.23	1.07	0.39	Yes
Autumn	2.17	2.28	1.12	0.23	Yes
Winter	2.42	2.53	1.12	-0.13	Yes
Spring	2.66	2.76	1.08	-0.33	No

Season	Mean	Median	Standard Deviation	Coefficient of Asymmetry	Normality Test
Gusts of wind ($m.s^{-1}$)					
2020					
Summer	6.12	5.99	1.58	1.23	Yes
Autumn	5.88	5.92	1.55	0.85	No
Winter	5.66	5.88	1.10	-0.36	Yes
Spring	6.26	6.39	1.26	-0.28	No
2021					
Summer	5.26	5.32	1.36	0.01	Yes
Autumn	5.07	5.16	1.50	0.11	Yes
Winter	5.57	5.68	1.52	-0.20	No
Spring	6.24	6.41	1.32	-0.62	Yes

*Circular descriptive measures for wind direction: Circular Mean, Circular Median, Circular Standard Deviation, and Circular Concentration Coefficient.

Source: Own elaboration.

Concerning wind speed, Table 2 indicates that, in 2020, all seasons of the year have similar average wind speeds. In 2021, in spring and winter, average wind speeds are slightly higher, with 2.66 $m.s^{-1}$ and 2.42 $m.s^{-1}$, respectively.

Silva et al. (1997), in Pelotas, RS, observed that the highest wind speeds are found in spring, and lower wind speeds occur in autumn. Wollmann and Galvani (2012), observe the action of the sea breeze during the daytime on the coast of RS, especially in spring and summer. In addition, the authors point out that in the Serra do Planalto of the Paraná Basin, the winds tend to be weaker during the summer months and at the beginning of the night. Rockett et al. (2017) identified higher average speeds in winter.

Finally, Table 2 indicates that, both in 2020 and in 2021, greater gusts (both in average and in terms of median) occur in spring.

Table 3 shows the comparison of the mesoregions in relation to wind direction, speed and gusts, in 2020 and in 2021. Regarding wind direction, it is possible to highlight that, both in 2020 and in 2021, the Nordeste Rio-Grandense mesoregion differs from the other mesoregions, with the exception of the Metropolitana de Porto Alegre mesoregion. In addition, in both years, the Sudoeste Rio-Grandense mesoregion differs from the other mesoregions, with the exception of the Centro Rio-Grandense mesoregion.

With regard to wind speed, comparisons are made based on non-parametric inference, as the speeds for the different mesoregions, in some cases, did not show normality based on the Shapiro-Wilk test. In 2020, the Nordeste Rio-Grandense mesoregion differs from the other mesoregions, with the exception of the Sudeste Rio-Grandense and Sudoeste Rio-Grandense mesoregions. The Sudeste Rio-Grandense mesoregion differs from all other mesoregions, with the exception of the Nordeste Rio-Grandense mesoregion.

In 2021, the Nordeste Rio-Grandense mesoregion differs from the other mesoregions, with the exception of the Centro Rio-Grandense and Sudeste Rio-Grandense mesoregions. The Sudeste Rio-Grandense mesoregion differs from the other mesoregions, with the exception of the Nordeste Rio-Grandense mesoregion.

Table 3 also presents the comparisons between the mesoregions, in both years, for wind gusts. Comparisons are performed based on non-parametric inference, as the gusts for the different mesoregions, in some cases, did not show normality based on the Shapiro-Wilk test. Note that the only change between the two years is that in 2020 the Centro Rio-Grandense and Nordeste Rio-Grandense mesoregions were different and became the same in 2021.

In both years, the Metropolitana de Porto Alegre mesoregion differed from the Nordeste Rio-Grandense and Sudeste Rio-Grandense mesorregions. In 2020, the Nordeste Rio-Grandense mesoregion differed from Centro Rio-Grandense, Metropolitana de Porto Alegre and Noroeste Rio-Grandense, and in 2021 it will no longer differ from Centro Rio-Grandense mesorregion. In both years, the Noroeste Rio-Grandense mesoregion differed from the Nordeste Rio-Grandense and Sudeste Rio-Grandense mesorregions. The Sudeste Rio-Grandense mesoregion differs from all other mesorregions, with the exception of Noroeste Rio-Grandense both in 2020 and 2021. The Sudoeste Rio-Grandense mesorregion does not differ from the others, except for the Sudeste Rio-Grandense mesorregion.

Table 3: Comparisons* between mesoregions using the Watson-Wheeler 2 to 2 test, with Bonferroni correction (for wind direction) and the Dunn test (for wind speed and gusts).

Comparisons for direction of wind					
2020					
	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	=	≠	=	=	=
Metropolitana		=	≠	=	≠
Nordeste			≠	≠	≠
Noroeste				=	≠
Sudeste					≠
2021					

	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	≠	≠	=	=	=
Metropolitana		=	=	=	≠
Nordeste			≠	≠	≠
Noroeste				=	≠
Sudeste					≠
Comparisons for speed of wind					
2020					
	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	=	≠	=	≠	=
Metropolitana		≠	=	≠	=
Nordeste			≠	=	=
Noroeste				≠	=
Sudeste					≠
2021					
	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	=	=	=	≠	=
Metropolitana		≠	=	≠	=
Nordeste			≠	=	≠
Noroeste				≠	=
Sudeste					≠
Comparisons for gusts of wind					
2020					
	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	=	≠	=	≠	=
Metropolitana		≠	=	≠	=
Nordeste			≠	=	=
Noroeste				≠	=
Sudeste					≠
2021					
	Metropolitana	Nordeste	Noroeste	Sudeste	Sudoeste
Centro	=	=	=	≠	=
Metropolitana		≠	=	≠	=
Nordeste			≠	=	=
Noroeste				≠	=
Sudeste					≠

*=equal. ≠different.

Source: Own elaboration.

Table 4 shows the comparisons of the seasons in relation to wind direction, speed and gusts, both in 2020 and in 2021.

In terms of wind direction, in 2020, all seasons differ from each other. In 2021, spring differs from the other seasons.

HOLOS
ISSN 1807 - 1600

Comparisons between the seasons, in relation to wind speed, are based on non-parametric inference, since the speeds for the different seasons of the year, in some cases, did not show normality based on the Shapiro-Wilk test. In 2020, there are no differences between the seasons. However, in 2021, spring differs from summer and autumn.

Concerning wind gusts, comparisons are made based on non-parametric inference, since the gusts for the different seasons of the year, in some cases, did not show normality based on the Shapiro-Wilk test. In 2020, spring differs from both autumn and winter. In 2021, spring differs from all other seasons.

Table 4: Comparisons* between seasons using the Watson-Wheeler 2 to 2 test, with Bonferroni correction (for wind direction) and the Dunn test (for wind speed and gusts).

Comparisons for direction of wind			
2020			
	Autumn	Winter	Spring
Summer	≠	≠	≠
Autumn		≠	≠
Winter			≠
2021			
	Autumn	Winter	Spring
Summer	=	=	≠
Autumn		=	≠
Winter			≠
Comparisons for speed of wind			
2020			
	Autumn	Winter	Spring
Summer	=	=	=
Autumn		=	=
Winter			=
2021			
	Autumn	Winter	Spring
Summer	=	=	≠
Autumn		=	≠
Winter			=
Comparisons for gusts of wind			
2020			
	Autumn	Winter	Spring
Summer	=	=	=
Autumn		=	≠
Winter			≠
2021			
	Autumn	Winter	Spring
Summer	=	=	≠
Autumn		=	≠
Winter			≠

*=equal. ≠different.

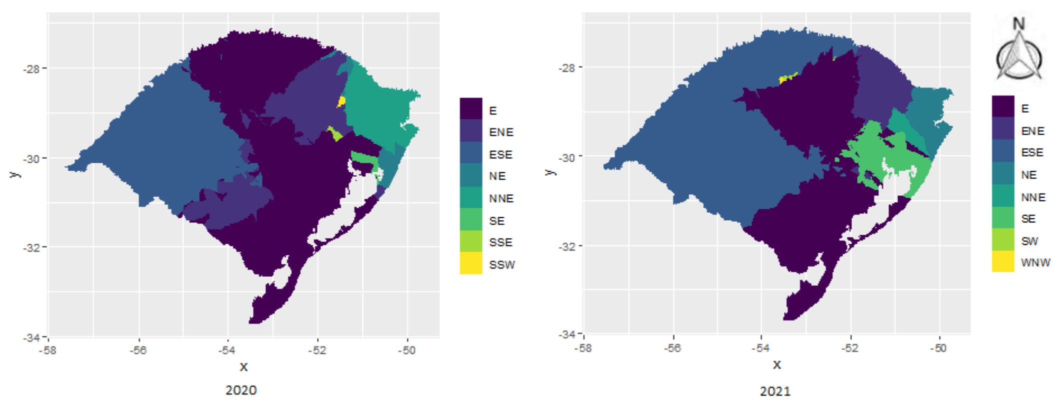
HOLOS ISSN 1807 - 1600

Source: Own elaboration.

The application of circular and non-parametric statistical methods allowed a relevant characterization of wind dynamics in the territory of Rio Grande do Sul, Brazil. The non-parametric statistical approach is already well established in the literature. However, the approach through circular statistics is still incipient, requiring more research and dissemination for better treatment of circular and directional data.

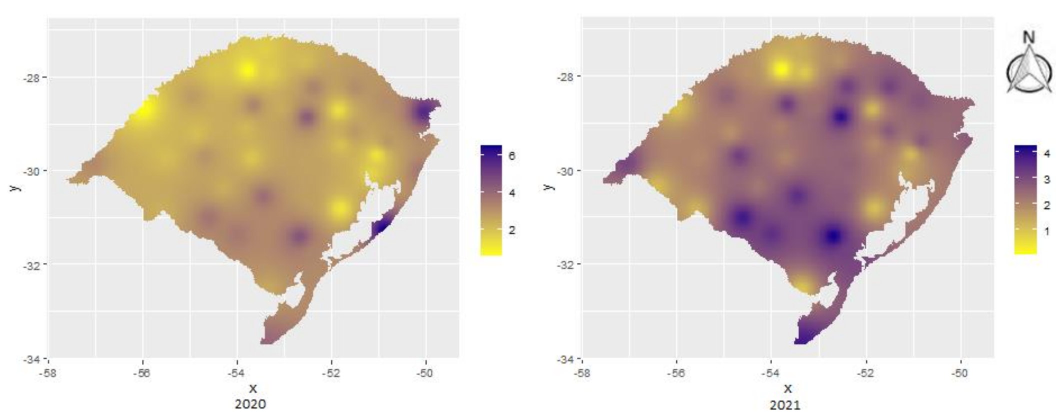
Most studies involving wind direction do not apply circular description and inference methods. This type of data has a distributional periodicity that is not similar to linear data; therefore, the use of appropriate statistical methodologies is paramount.

Figures 2, 3 and 4 show, respectively, the spatial predictions for wind direction (in the form of cardinal points), for wind speed ($m.s^{-1}$) and for wind gusts ($m.s^{-1}$).



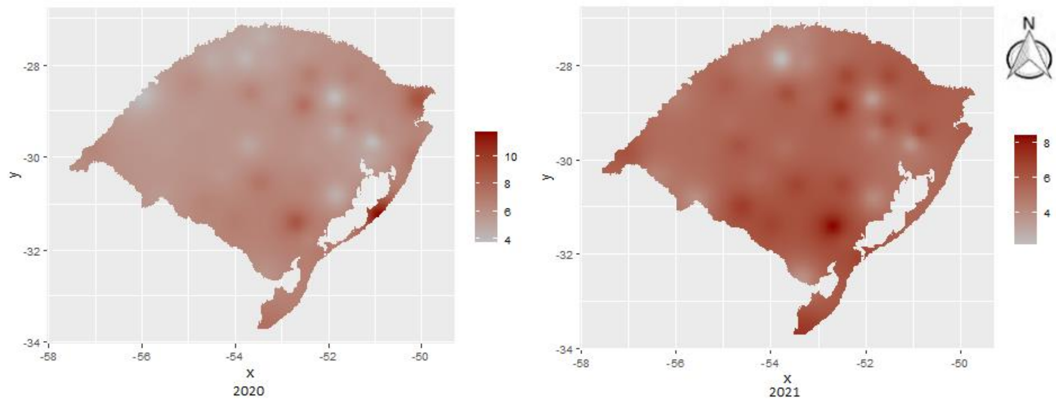
Source: Own elaboration. *Image created in R.

Figure 2: Spatial prediction of wind direction (in cardinal points format) in the state of Rio Grande do Sul, Brazil, in the years 2020 and 2021.



Source: Own elaboration. *Image created in R.

Figure 3: Spatial prediction of wind speed (m.s^{-1}) in the state of Rio Grande do Sul, Brazil, in the years 2020 and 2021.



Source: Own elaboration. *Image created in R.

Figure 4: Spatial prediction of wind gusts (m.s^{-1}) in the state of Rio Grande do Sul, Brazil, in the years 2020 and 2021.

Based on Figure 2, it can be observed that, in general, the areas to the west, northwest, and part of the center have a predominance of winds in the ESE direction; the areas to the south, part of the center, and north have a predominance of winds in the E and ENE directions; The Metropolitana de Porto Alegre mesoregion has winds predominantly in the E and SE directions; and the regions to the northeast and east of the RS present winds in the NNE, NE and ENE directions.

Figure 2 was generated using the kNN method, as the wind direction data were categorized into 16 classes. Previous studies, such as Bonisch et al. (2004), Yamamoto et al. (2012), and Costa et al. (2019), also applied spatial interpolation methods to categorical data, highlighting different approaches and methodological challenges. Thus, this remains a topic of ongoing discussion in the literature.

From Figures 3 and 4, there is a predominance of higher wind speeds (tending to values greater than 3 m.s^{-1}) and gusts (tending to values greater than 6 m.s^{-1}) in the southern and coastal areas of RS; the lowest wind speeds and gusts are seen in areas further north and northwest of RS. The wind atlas of Rio Grande do Sul (SEMC, 2002) and the Brazilian wind potential atlas (AMARANTE et al., 2001) indicate the wind potential of the southern coastal region of Brazil with predominant east-northeast winds with more than 7 m.s^{-1} at 50 meters height.

It is worth noting that wind variability can be influenced by external factors not directly considered in this study. Future research could incorporate atmospheric circulation models and orographic variables to provide a more comprehensive assessment of how these factors affect wind dynamics in Rio Grande do Sul.

Understanding wind behavior can support architectural and agricultural planning, wind energy projects, and the prevention of damage caused by strong winds. The results may inform natural disaster mitigation policies and sustainable land-use planning. Therefore, further research is needed to explore the full characteristics and dynamics of wind by extending the time series of analysis, considering spatiotemporal interactions, and linking them to the potential impacts on the population of Rio Grande do Sul, Brazil.

4 CONCLUSION

Both for the mesoregions and for the seasons, there is a predominance of winds in the east and east-southeast directions, being concentrated winds and with little directional variability.

The winds present both higher average speeds and higher average gusts in the southern and coastal regions of the state of Rio Grande do Sul. The lowest speeds and smallest gusts are observed in the North/Northwest of the state of Rio Grande do Sul.

Thus, this study contributes to the understanding of the spatial and temporal variability of winds in Rio Grande do Sul. It highlights the influence of mesoregions on wind dynamics, reinforcing the importance of detailed regional analyses.

5 REFERENCES

Agostinelli, C. & Lund, U. (2022). R package 'circular': Circular Statistics (version 0.4-95). https://r-forge.r-project.org/projects/circular/.

Almeida, L. O., Lima, M G., Esteves, I. C. A., Munhoz, G. S., & Medeiros-Junior, R. A. (2021). Updating the Brazilian wind speed map for structural design. *Structural Engineering and Mechanics*. 79(5), 557-564. https://doi.org/10.12989/sem.2021.79.5.557.

Alves, E. D. L., & Silva, S. T. (2011). Direção e velocidade do vento em uma floresta de transição amazônia-cerrado no norte de Mato Grosso, Brasil. *Boletim Goiano de Geografia*, 31(1), 63-74. https://doi.org/10.5216/bgg.V31i1.15400.

Amarante, O. A. C., Brower, M., Zack, J. & Sá, A. L. (2001). *Atlas do potencial eólico brasileiro*. Brasília.

Araújo Júnior, G. N., Queiroz, M. G., Jardin, A. M. R. F., Silva, M. J., Pereira, P. C., & Silva, T. G. F. (2019). Caracterização da direção predominante, velocidade máxima e média do vento do município de Petrolina-PE. *Pensar acadêmico*, 17(1), 43-49. https://doi.org/10.21576/pa.2019v17i1.363.

Back, A. J. (2020). Informações climáticas e hidrológicas dos municípios catarinenses (com programa HidroClimaSC). Epagri.

Bárbara Neto, M., Boeira, L. S., Neves, L. A., & Terra, V. S. S. (2021). Velocidades e direções predominantes dos ventos associadas a períodos secos e chuvosos em uma bacia litorânea. *Revista Ibero-Americana de Ciências Ambientais*, 12(11), 98-108. https://doi.org/10.6008/CBPC2179-6858.2021.011.0010.

Bonisch, S., Assad, M. L. L., Monteiro, A. M. V., & Câmara, G. (2004). Representação e propagação de incertezas em dados de solo. II - Atributos numéricos. *Revista Brasileira de Ciências do Solo*, 28(1), 33-47. https://doi.org/10.1590/S0100-06832004000100004.

Borges, T. K. S., Oliveira, A. S., & Silva, N. D. (2018). Análise da velocidade e direção dos ventos em Cruz das Almas, Bahia, no período 1973-2001. *Revista Semiárido De Visu*, 6(3), 122-134. https://periodicos.ifsertao-pe.edu.br/ojs2/index.php/semiaridodevisu/article/view/446.

Castelhano, F. J., & Roseghini, W. F. F. (2018). Caracterização da dinâmica dos ventos em Curitiba-PR. *GEOUSP*, 22(1), 227-240. http://dx.doi.org/10.11606/issn.2179-0892.geousp.2018.123088.

Costa, H. S., Seidel, E. J., Pazini, J. B., Silva, A. M., Silva, F. F., Martins, J. F. S., Barrigossi, J. A. F. (2019). Mapping of spatiotemporal distribution of Tibraca limbativentris Stal (Hem.: Pentatomidae) in flooded rice crop in Southern Brazil. *Revista Brasileira de Entomologia*, 63(3), 205-211. https://doi.org/10.1016/j.rbe.2019.04.001.

Dinno, A. (2017). dunn.test: Dunn's Test of Multiple Comparisons Using Rank Sums. R package version 1.3.5. https://CRAN.R-project.org/package=dunn.test.

Favera, A. C. D., Luiz, E. W., Schuch, N. J., Martins, F. R., & Pereira, E. B. (2012) Potencial eólico no Rio Grande do Sul - Distribuição estatística dos ventos na região central do estado. *Revista Geográfica Acadêmica*, 6(1), 38-51.

Fisher, N. I. (1993). Statistical Analysis of Circular Data (1. ed.). University Press.

Komsta, L., & Novomestky, F. (2015). moments: Moments, cumulants, skewness, kurtosis and related tests. R package version 0.14. https://CRAN.R-project.org/package=moments.

Lima, R. G., & Bittencourt, L. S. (2017). A influência de diferentes arranjos construtivos no comportamento da ventilação natural. *Urbe. Revista Brasileira De Gestão Urbana*, 9, 425–441. https://doi.org/10.1590/2175-3369.009.SUPL1.AO013.

Mendiburu, F. (2021). agricolae: Statistical Procedures for Agricultural Research. R package version 1.3-5. https://CRAN.R-project.org/package=agricolae.

Munhoz, F. C., & Garcia, A. (2008). Caracterização da velocidade e direção predominante dos ventos para a localidade de Ituverava-SP. *Revista Brasileira De Meteorologia*, 23(1), 30-34. https://doi.org/10.1590/S0102-77862008000100003.

Pebesma, E. J. (2004). Multivariable geostatistics in S: the gstat package. *Computers & Geosciences*, 30(7), 683-691. https://doi.org/10.1016/j.cageo.2004.03.012.

Pewsey, A., Neuhauser, M., & Ruxton, G. D. (2013). Circular Statistics in R (1. ed.). Oxford Univercity Press.

Ponciano, A. C., & Back, A. J. (2022). Caracterização do regime de ventos em Laguna, Santa Catarina. *Revista Técnico-Científica de Engenharia Civil Unesc*, 7(2), 1-14. https://doi.org/10.18616/civiltec.v7i2.7413.

Pontes, A. K. S., Dias, G. F. M., & Souza, A. M. L. (2018). Caracterização da velocidade e direção predominante dos ventos no litoral do nordeste paraense. *Revista Brasileira de Iniciação Científica*, 5(1), 33-42.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Ramos, H., Pontes, B., & Pantoja, P. (2021). Análise da direção e da velocidade do vento em Vitória-ES: um estudo preliminar. *Revista Científica Foz*, 1-20.

Rockett, G. C., Telles, P., Barboza, E. G., Gruber, N. L. S., & Simão, C. E. (2017). Análise espaço-temporal dos ventos no extremo norte da Planície Costeira do Rio Grande do Sul, Brasil. *Pesquisas Em Geociências*, 44(2), 203–219. https://doi.org/10.22456/1807-9806.78271.

Santos, S. D., Seidel, E. J., & Silva, A. M. (2019). *Estudo da direção do vento nas mesorregiões do Rio Grande do Sul* [Resumo expandido]. 64ª Reunião Anual da Região Brasileira da Sociedade Internacional de Biometria (RBras) e 18º Simpósio de Estatística Aplicada à Experimentação Agronômica (SEAGRO), Piracicaba, SP.

Schliep, K., & Hechenbichler, K. (2016). kknn: Weighted k-Nearest Neighbors. R package version 1.3.1. https://CRAN.R-project.org/package=kknn.

Secretaria de Energia, Minas e Comunicações (SEMC) (2002). *Atlas eólico: Rio Grande do Sul*. Porto Alegre.

Silva, M. F., & Barbosa, R. V. R. (2022). Regime de ventos em cidades de diferentes regiões geográficas de Alagoas a partir de dados meteorológicos recentes. *Revista Brasileira De Climatologia*, 31(18), 509–538. https://doi.org/10.55761/abclima.v31i18.15606.

Silva, R. L., & Vieira, M. M. (2016). DIREÇÃO PREDOMINANTE, VELOCIDADE DO VENTO E SUAS FREQUÊNCIAS DE OCORRÊNCIA EM DOURADOS-MSS. *ENERGIA NA AGRICULTURA*, 31(4), 348–355. https://doi.org/10.17224/EnergAgric.2016v31n4p348-355.

Silva, J. B., Zanusso, J. T., Silveira, D. L. M., Schons, R. L., & Larroza, E. G. (1997). Estudo da velocidade e direção dos ventos em Pelotas, RS. *Revista Brasileira de Agrometeorologia*, 5(2), 227-235.

Sobral, B. S., Oliveira Júnior, J. F. de ., Gois, G. de ., Terassi, P. M. de B., & Pereira, C. R. (2018). Regime de Vento na Serra do Mar - Rio de Janeiro, Brasil. *Revista Brasileira De Meteorologia*, 33(3), 441–451. https://doi.org/10.1590/0102-7786333004.

Terassi, P. M. B., Oliveira-Júnior, J. F., Galvani, E., Correia Filho, W. L. F., Góis, G., Sobral, B. S., & Biffi, V. H. R. (2019). Regime de ventos em Curitiba e Paranaguá, Paraná. *Revista Brasileira de Climatologia*, 25, 294-318. http://dx.doi.org/10.5380/abclima.v25i0.65645.

Yamamoto, J. K., Mao, X. M., Koike, K., Crosta, A. P., Landim, P. M. B., Hu, H. Z., Wang, C. Y., Yao, L. Q. (2012). Mapping an uncertainty zone between interpolated types of a categorical variable. *Computers & Geosciences*, 40 (1), 146-152. https://doi.org/10.1016/j.cageo.2011.09.005.

Wahrlich, J., Silva, F. A., Campos, C. G. C., Rodrigues, M. L. G., & Medeiros, J. (2018). Characterization of the predominant wind speed and direction in Santa Catarina, Brazil. *Revista Brasileira de Climatologia*, 23, 356-373. http://dx.doi.org/10.5380/abclima.v23i0.57115.

Wollmann, C. A., & Galvani, E. (2012). Caracterização climática regional do Rio Grande do Sul: dos estudos estáticos ao entendimento da gênese. *Revista Brasileira de Climatologia*, 11, 87-103. http://dx.doi.org/10.5380/abclima.v11i0.28586.

World Meteorological Organization (WMO) (2008). *Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8)*.

HOW TO CITE THIS ARTICLE:

Santos, S. D., Leonardi, I. S., Cassenote, M. de D., Silva, A. M., & Seidel, E. J. Variabilidade regional do vento no estado do Rio Grande do Sul, Brasil. HOLOS, 7(41). https://doi.org/10.15628/holos.2025.15955

ABOUT THE AUTHORS:

S. D. SANTOS

Universidade Federal de Santa Maria (UFSM)

ORCID:https://orcid.org/0000-0003-2854-0378

I. S. LEONARDI

Universidade Federal de Santa Maria (UFSM)

ORCID:https://orcid.org/0009-0009-7769-9757

M. D. CASSENOTE

Universidade Federal de Santa Maria (UFSM)

ORCID:https://orcid.org/0009-0004-9719-1049

A.M. SILVA

Universidade Federal de Santa Maria (UFSM)

ORCID:https://orcid.org/0000-0002-3230-3343

E. J. SEIDEL

Universidade Federal de Santa Maria (UFSM)

ORCID:https://orcid.org/0000-0002-9656-0699

Editor : Francinaide de Lima Silva Nascimento

***Ad Hoc* Reviewer:** Rafael Vieira do Vale

Received: August 31, 2023

Accepted: September 23, 2025

Published: December 30, 2025