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Power parameters for spatialization the speed and gust of wind to a region of the sub-medium part of São Francisco, Brazil

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ABSTRACT

As the average velocity and gust of wind present stability with varying distances, they allow in a simpler way the creation of continuous fields using spatial interpolation methods. The objective of this work was to obtain the power parameters for the Inverse Distance Power (IPD) interpolation method, in the spatialization of daily values of the average velocities (V_v) and wind gust (V_r), during the annual, winter, spring, summer and autumn in the sub-medium part of São Francisco region, Brazil. The power (p) parameters of the IPD of the average velocities and wind gust velocity. The minimum MAE values for V_v were 0.57; 0.63; 0.59; 0.45 and 0.62 m s⁻¹ for the annual, winter, spring, summer and autumn, respectively, with corresponding p values equal to 3.4; 3.6; 2.9; 4.2 and 3.1. And for V_r , they were 0.89; 0.99; 0.86; 0.75 and 1.01 m s⁻¹ with corresponding values of p , 3.3; 3.6; 2.9; 4.2 and 3.1 for the same periods. There is agreement between the measured and estimated values of V_v and V_r using the data of the second period, obtained with the cross-validation methodology, with R^2 values of 98.68% and 98.79%, respectively.

Keywords: interpolation, cross-validation, weather station, Brazilian Northeast, continuous areas.

Parâmetros de potência para espacialização da velocidade e rajada do vento para uma região do submédio de São Francisco, Brasil

RESUMO

O conhecimento de características ambientais, em particular variáveis meteorológicas, é fundamental para subsidiar as tomadas de decisão e o gerenciamento ambiental. Como a velocidade média e rajada do vento apresentam estabilidade com distâncias variadas, permite de uma maneira simples a criação de campos contínuos utilizando métodos de interpolação espacial. O objetivo deste trabalho foi obter os parâmetros de potência através do método de interpolação do Inverso da Potência da Distância (IPD), na espacialização de valores médios diários das velocidades médias (V_v) e rajada (V_r) do vento, para o período de um ano, nas estações de inverno, primavera, verão e outono para região do Submédio São Francisco. Foram obtidos os parâmetros de potência (p) do interpolador IPD das velocidades médias e rajadas do vento. Os valores mínimos de MAE para V_v de 0,57; 0,63; 0,59; 0,450 e 0,62 m s⁻¹ para inverno, primavera, verão e outono, com p valores de 3,4; 3,6; 2,9; 4,2 e 3,1 respectivamente. E para V_r de 0,89; 0,99; 0,86; 0,75 e 1,01 m s⁻¹ com p valores de 3,3; 3,6; 2,9; 4,2 e 3,1 respectivamente. Verifica-se concordância entre os valores medidos e estimados da V_v e V_r utilizando os dados do segundo período foram comparados através metodologia de validação cruzada, com valores de R^2 de 98,68% e de 98,79%, respectivamente. O erro absoluto médio é a melhor medida de desempenho do IPD para a espacialização da V_v e V_r . Os valores de erro médio foram pequenos, quando comparado com a grandeza dos valores e próximos ao erro instrumental.

Keywords: interpolação, validação cruzada, estação meteorológica, Nordeste do Brasil, campos contínuos.

Introdução

The knowledge of environmental characteristics, especially meteorological elements, is fundamental to support decision making and environmental management. The evapotranspiration (ET_o) reference obtained through meteorological elements is of fundamental importance for obtaining the hydro-meteorological characterization to be used in agriculture, as well as in water resources management and applications in the environmental modelling (Zhang et al., 2010).

From meteorological elements applied to the sub-medium region of São Francisco, Prado and Leal (2017) observed that the wind speed (at 2 meters high), maximum temperature, minimum relative humidity and solar radiation are the aspects that more explained the variations of ET_o. With these data, they observed the consistency of temperature, humidity, wind and solar radiation sensors for INMET stations in the region.

Among the meteorological variables required for the calculation of the water balance, the wind speed and wind gust, which presents a continuity in the distance quantitative, are highlighted, thus allowing the creation of continuous fields using spatial interpolation methods, as observed for meteorological variables by Cardoso et al. (2013), even for variables that have high spatio-temporal variability (Lopes et al., 2016). In this way it is possible to estimate meteorological data for places where there is no disposition of active meteorological stations.

Taking into account the great importance for the application in agriculture, in order to know the environmental conditions and later water economy, it was designed to characterize renewable energy potentials, which require accurate information and all its mapping of the measures in the long term (Teksoy et al., 2015).

However, the environmental characterization through meteorological elements is limited to regions that have meteorological stations. Thus, the methodology of interpolation can supply a great need of users of meteorological data where there are not such stations (Siqueira et al., 2018).

A methodology that already has good precision is the Inverse of the Power of Distance (IPD), which has a similar principle to the idea of

proximity applied in the methodology of the Thiessen polygons (Thiessen, 1911), thus allowing to create a trend surface with meteorological data and with wide forms of application in agriculture. In this way, the meteorological stations that are closer to the place of acquisition of data will have more influence in the value to be obtained.

In order to evaluate the errors of the spatial interpolators, the mean absolute error (MAE) and the mean bias (VM) were determined by Willmott and Matsuura (2006). In addition to the application in meteorology, there are several studies that consolidate verification in other fields of science, as described by Delgado et al. (2012) and Borges Júnior et al. (2012).

Considering the importance of the meteorological variables for the calculation of the evapotranspiration reference (ET_o), of the water balance and also due to the lack of bibliography related to the spatialization of meteorological variables for the region development of the sub-medium of São Francisco, Brazil, the objective of this work was to obtain the parameters of power for the IPD interpolation method, in the spatialization of daily values of the average velocities and gust wind of this region for a one-year for the winter, spring, summer and autumn.

Material and methods

Study area

The study area comprises a large part of the sub-medium of São Francisco, corresponding to the Petrolina-Juazeiro Development Pole, located in one of the most arid zones of the Brazilian Northeast, on the São Francisco River, in the extreme West of Pernambuco and North of Bahia, Brazil. It has public irrigation perimeters (CODEVASF, 2018).

In Figure 1, the scope of the present work is represented cartographically through a circle of approximately 250 km radius around the city of Petrolina-PE, in the Northeastern Semi-arid Brazilian.

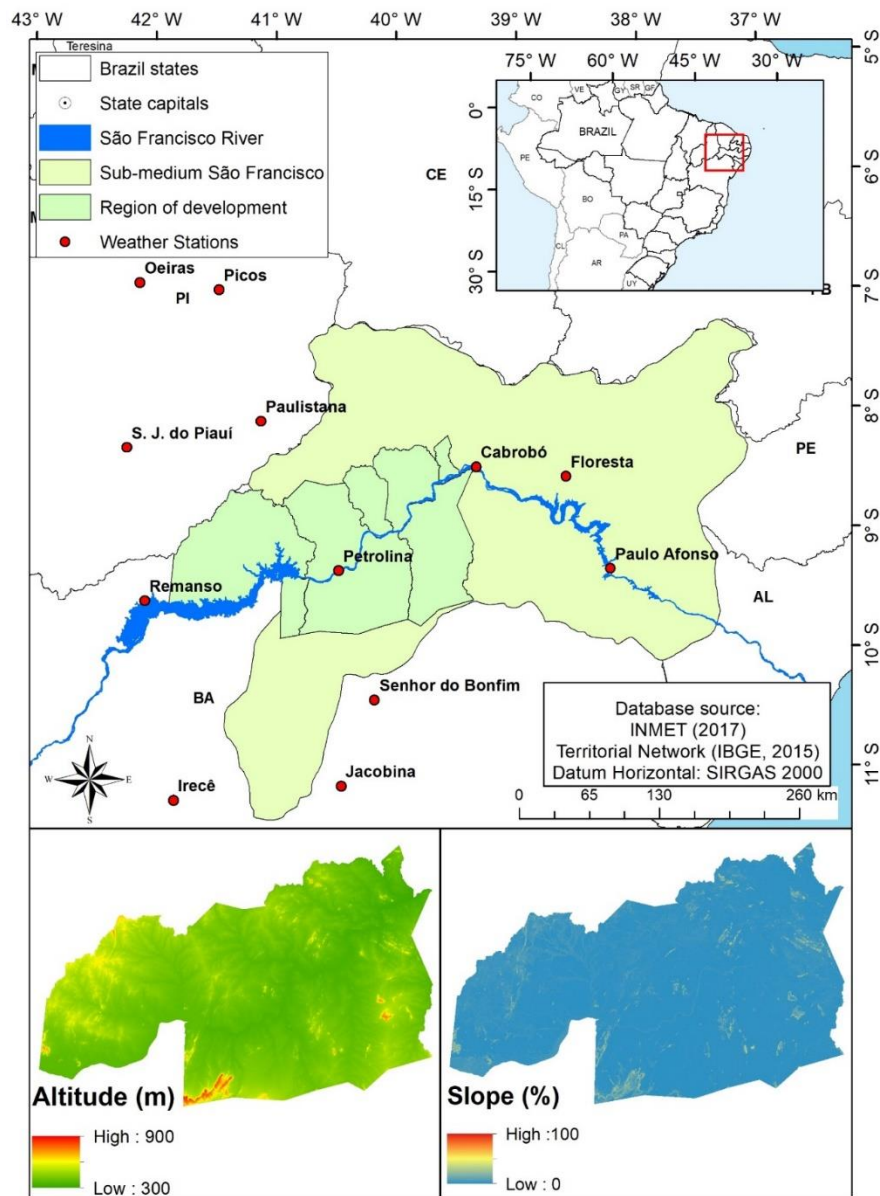


Figure 1. INMET's area of spatialization study of the automatic stations used. With reference of Petrolina's station in the state of Pernambuco.

For the study, hourly data were obtained from 14 automatic meteorological stations of the National Institute of Meteorology (INMET) in operation in the studied area, with their respective INMET code: Cabrobó - PE (A329), Delfino - BA (A443), Euclides da Cunha - BA (A442), Floresta - PE (A351); Irecê - BA (A424); Jacobina - BA (A440); Paulistana - PI (A330); Petrolina - PE (A307); Queimadas - BA (A436); Remanso - BA (A423); São João do Piauí - PI (A331); São Raimundo Nonato - PI (A345); Senhor do Bonfim - BA (A428); Uauá - BA (A435).

Periods studied

By obtaining the hourly values of the mean velocity and the wind gust, only days that had at least 18 valid hourly data were used.

These data were organized in two periods and five seasons each, as described: first period from 06/21/2008 to 06/20/2009, with their respective seasons, winter (21/06/2008 to 22/09/2008), spring (23/09/2008 to 20/12/2009), summer (21/12/2008 to 20/03/2009) and autumn (03/21/2009 to 06/20/2009), these data were used to estimate the values of p of these epochs considered; the second period (06/21/2009 to 06/21/2010) the data were used to evaluate the power value error, when estimating data using the values of p obtained in the first period.

Estimation of IPD power parameters

For the spatialization of the values of the average velocity and the daily wind gust, the powers were evaluated for the power inversion n interpolation (IPD) method, considering for the calculations the 8 nearest neighbors. The power parameter varied from 0.0 to 25.0, with increment of 0.1 according to the methodology proposed by Lopes et al. (2017) and Lopes and Leal (2018).

The IPD methodology takes into account that the quantitative of the variable, to be estimated in any position, is calculated by its neighbors and thus weighted by the inverse of its elevated distance to a power "p", according to Eq. 1.

The performance of the IPD was determined using the Mean Absolute Error (MAE) (Eq. 2) and Mean Bias (VM) values (Eq. 3), calculated using the Cross-Validation (VC) technique applied to the data of the first period.

$$f_e(r) = \frac{\sum_{i=1}^n d(r, r_i)^{-p} f_m(r_i)}{\sum_{i=1}^n d(r, r_i)^{-p}} \quad \text{Eq. 1}$$

$$MAE = \frac{1}{n} \sum_{i=1}^n |f_m(r_i) - f_e(r_i)| \quad \text{Eq. 2}$$

$$VM = \frac{1}{n} \sum_{i=1}^n [f_m(r_i) - f_e(r_i)] \quad \text{Eq. 3}$$

In which,

$f_e(r)$ - estimated value of f in the position vector r,

$f_m(r_i)$ - measured value of f in the position vector r_i ,

n - total number of points known and used in the interpolation,

$d(r, r_i)$ - Euclidean distance between the vectors r and r_i , and

p - power parameter.

In the elaboration of VC, the calculated values with data of less than 10 automatic meteorological stations were disregarded. In this stage, the year season's power values (winter, spring, summer and autumn) were obtained.

The data were cross-validated according to the methodology of Robinson and Metternicht (2006) and Amorim et al. (2008). This methodology consists of discarding a point of measurement and performs the interpolation successively, making it possible to obtain the

estimated value (m) relative to the withdrawn value and compare it with the real value of variable (e).

Assessment of p value

The p value of the year period, obtained with the data from the first period, was evaluated using the data from the second period by means of the values of the average daily error, as defined below:

- Relative error of the average wind speed and the daily wind gust (erday), the relative error calculated from the estimated values of the daily average speed and the wind gust (X_e) and the measured values of the daily average wind speed and the wind gust (X_m) in a weather station, Eq. 4.

- mean relative error of the average velocity and the daily wind gust (ermid), the ermid arithmetic average of a set of meteorological stations, Eq. 5.

$$re_{day} = \frac{X_m - X_e}{X_m} \quad \text{Eq. 4}$$

$$er_{mid} = \text{mean}\{er_{day}\} \quad \text{Eq. 5}$$

Results and discussion

Characterization of wind data.

From the first period it was used 4883 and 4893 values of the average velocity (Vv) and the wind gust (Vr), respectively. They were calculated using hourly data measured in the meteorological stations. The minimum, medium, median, maximum, first quartile (Q 1/4) and third quartile (Q 3/4) values of the data used at each time in the first period are presented in Figure 2.

The characterization of Vv and Vr can be observed, highlighting the studied times, when it was observed the presence of outliers for Vv and Vr for winter and summer, and only for Vr in spring and autumn, with the exception of the year period. These values did not cause significant changes in the interpolations. In addition, they corroborate with the observations made by Liska et al. (2013) who noted the extreme variations in wind speed, being associated with a recurrence time.

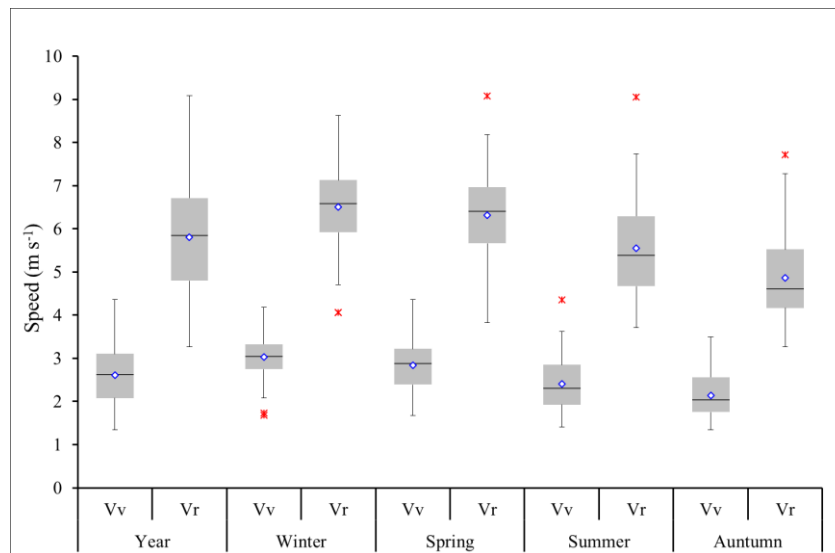


Figure 2. Box plot of the data of average velocity (Vv) and gust of wind (Vr) used at the times: year, winter, spring, summer and autumn of the first period.

The values of standard deviation obtained between the data set for Vv and Vr, as can be observed in Table 1, demonstrate that the values represent satisfactorily the variability of the two meteorological variables used in the calculation

and that they contribute, with its lower variation, to the interpolation success. The standard deviation values of Vr are slightly higher than Vv, which is directly connected with the variability of the measurement.

Table 1. The average velocity and the wind gust statistics for the first period and its times (year, winter, spring, summer, autumn) for the sub-medium part of São Francisco.

	Wind speed			
	Mean (Vv)		Gust (Vr)	
	S	N	S	N
Year	0.13	4883	0.87	4893
Winter	0.01	1421	0.61	1423
Spring	0.19	1419	0.90	1426
Summer	0.29	1394	0.55	1396
Autumn	0.01	1146	0.70	1281

* s = standard deviation; n = number of data used.

Characterization of wind data

In Figures 3A and 3B the variation of the Mean Absolute Error (MAE), as a function of power at the times and in the periods studied, can

be verified. The variation of this error was similar at all times, with a higher value in the initial powers, accompanied by a subtle reduction to a minimum value, followed by the recovery of the error elevation.

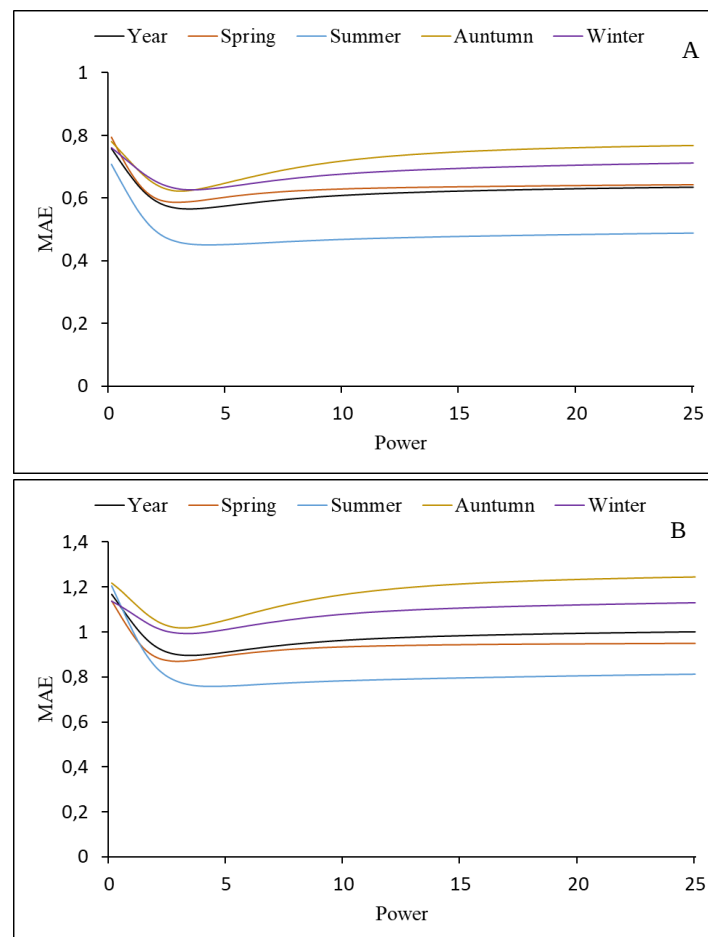


Figure 3. Mean Absolute Error of the powers calculated for the years and for the seasons year, winter spring, summer and autumn of the first period, for Average Speed (A) and gust (B) of the wind.

The minimum MAE values for the average wind speed were 0.57; 0.63; 0.59; 0.45 and 0.62 m s^{-1} for the year period, winter, spring, summer and autumn, respectively, with corresponding p values equal to 3.40; 3.60; 2.90; 4.20 and 3.10. For the same sequence of times, MAE values for burst velocity were 0.895; 0.993; 0.869; 0.758 and 1.017 m s^{-1} with corresponding values of p, 3.30; 3.60; 2.90; 4.20 and 3.10. In general, it is visualized there was a small influence of the seasonality in the temporal scales considered.

Due to the fact that the values of p obtained using MAE are greater than 1.0, a greater influence of the values closer to the interpolated point can be pointed, this explanation is associated to the spatial stability and continuous field, that is the wind itself.

When the value of p is obtained closer to the natural conditions, there is an ease in applications, which are of fundamental importance for the quality of obtaining data of Vv and Vr for locations that do not have stations, therefore they are essential for the calculation of ETo (Lopes and Leal, 2016) and for the generation of renewable energy (Santos et al., 2017; Lima et al., 2010) since

the area does not have a larger number of public stations of INMET nor the Brazilian Agricultural Research Company (EMBRAPA).

Paula et al. (2017) concluded that the maps of wind velocity generated can be used in the pre-identification of the best areas for eolic-electric projects. However, because of the sensitivity of the wind to the local characteristics of relief, roughness, obstacles and thermal conditions of the atmosphere, the values presented by the maps generated in this work can vary significantly depending on the local conditions, thus, this interpolation study increases the quality and data availability for non-sampled points.

In addition, these p data for spatialization of wind velocities can contribute to verifications of the climate changes' perception over time, in places that do not have meteorological data, as well as the absence of a historical series, as shown in the studies done by Silva and Azevedo (2008) about variations in weather elements and other climatic factors.

Figures 4A and 4B show the variation of VM as a function of p at the times and the periods studied, for average velocity (Vv) and gust of wind

(Vr). For Vv, the general variation of the MV was similar at the times, with close initial values, accompanied by a sharp increase until a maximum value for autumn and winter. For year, summer and spring the same tendency occurred, but with lower values. The year curve was the intermediate one

with a small VM oscillation, presenting a minimum value at the beginning and adding a gradual value until near power 5 and thus continuing almost invariable up to p of 25. For Vr, it followed the same distribution pattern of the curves of the minimum, with only an increase of values.

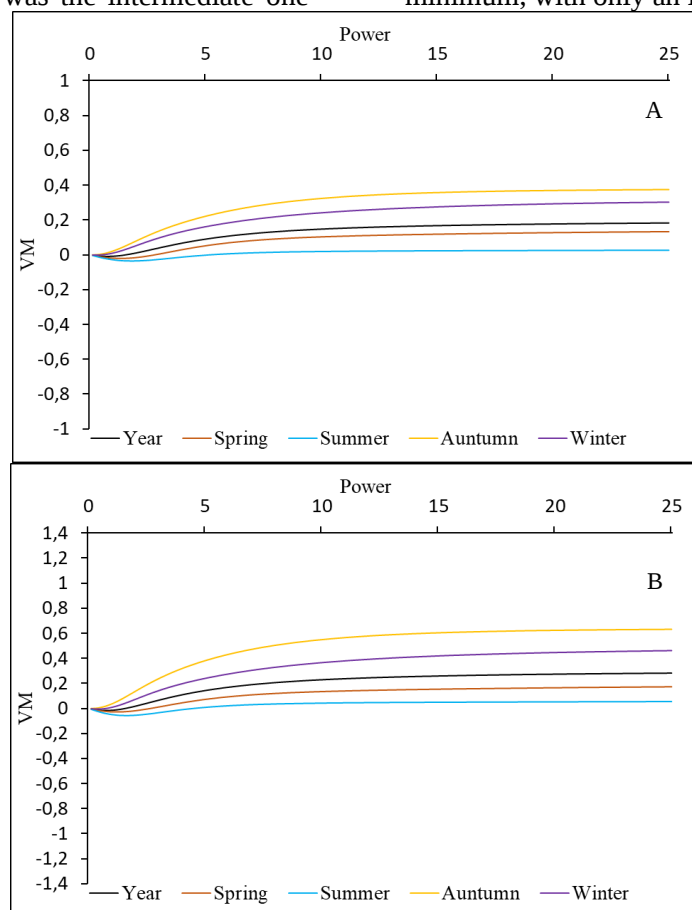


Figure 4. Average Bias of the powers calculated for the years and for the winter spring, summer and autumn of the first period, for Average Speed (A) and gust (B) of the wind.

The meteorological elements in the region and in the studied period, which are better evaluated by statistical analysis comparing the MAE and MV behavior in the spatial interpolation, allow us to infer that both errors, due to having a similar behavior for the times and presenting a single point of minimum, corroborate the results obtained by Willmott and Matsuura (2006).

Estimated power value performance

The efficiency of the interpolation method for application in the wind velocity parameter in the sub-medium of São Francisco region can be observed in Figures 5A and 4B, where the minimum difference between the estimated values is shown.

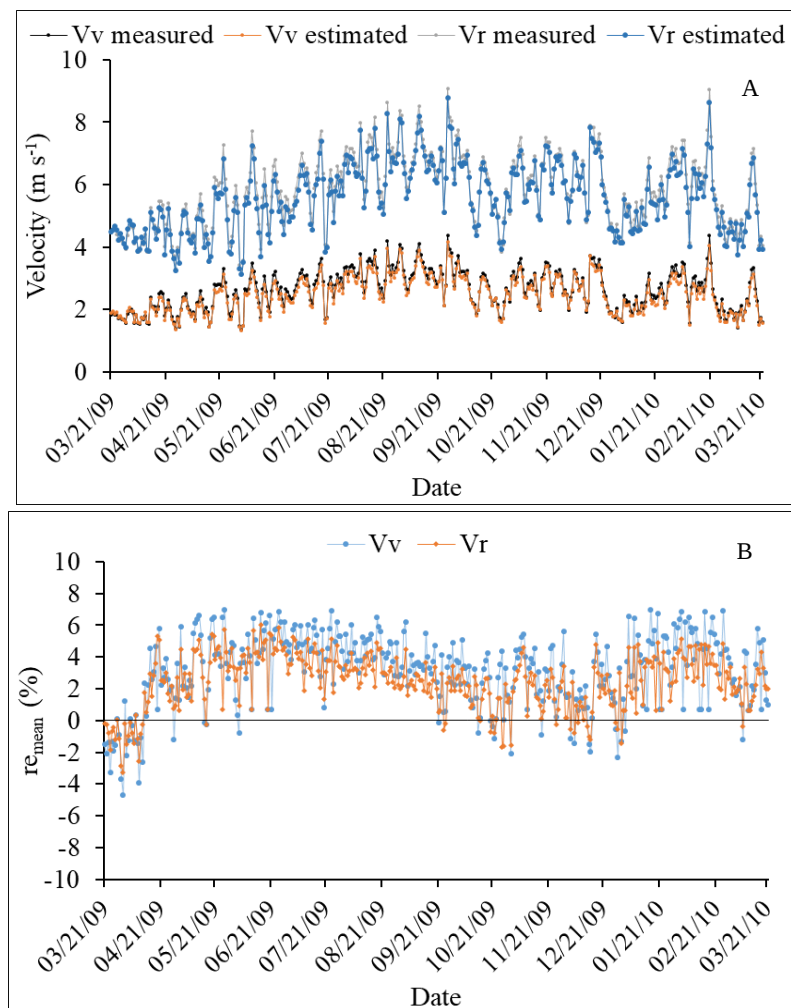


Figure 5. Average Bias of the powers calculated for the years and for the winter spring, summer and autumn of the first period, for Average Speed (A) and gust (B) of the wind.

The accuracy in meteorological variables for a similar methodology to this study has also been verified by Perin et al. (2015), reporting that the interpolation method is effective for the estimation of these elements, with wide application in wind speed and gust acquisition in a spatialized way.

In Figure 6 we can observe the daily variations of the mean (ermid) relative errors calculated using the average speed wind and wind gust data of the second period using the p value obtained for the year time, $p = 3.4$ and $p = 3$, respectively.

It can be observed that the variation of ermid is of a random nature, with proximity of the error value 0. In general, ermid values were small, for Vv it varied from -7.5 to 4.9% and average of 0.7% and for Vr ranged from -9.5 to 3.2% and average of -1, 2%. These values, which are no longer significant, can still be related to the sensor's accuracy range, which ranges from -5 to 5% (Vaisala, 2011).

For studies with meteorological data, measured and estimated values are not always obtained as close as those observed for average

wind and gust velocity. In the case of some studies that did not obtain such precision between the two values, they were observed in the performance studies of different interpolator methods for meteorological variables of Castro et al. (2010) and of Cecílio et al. (2012). This result, which was obtained in the respective studies, differ to the observed and the estimated ones and also may be related to the choice of the best power for the method, whose authors fixed the power in a unit value, while the current study ranged from decimal to power 25.

The effectiveness of the power application with the lowest interpolation MAE for the average wind and gust velocity data for the region is noteworthy. The correlation between measured and estimated wind data can be seen in Figure 4C and 4D.

Although the locations of the meteorological stations are quite dispersed and with different distances from each other, it is possible to verify agreement between the measured and estimated values of Vv and Vr using data of the

second period, with $R^2 = 98.68\%$ and $R^2 = 98.79\%$, respectively.

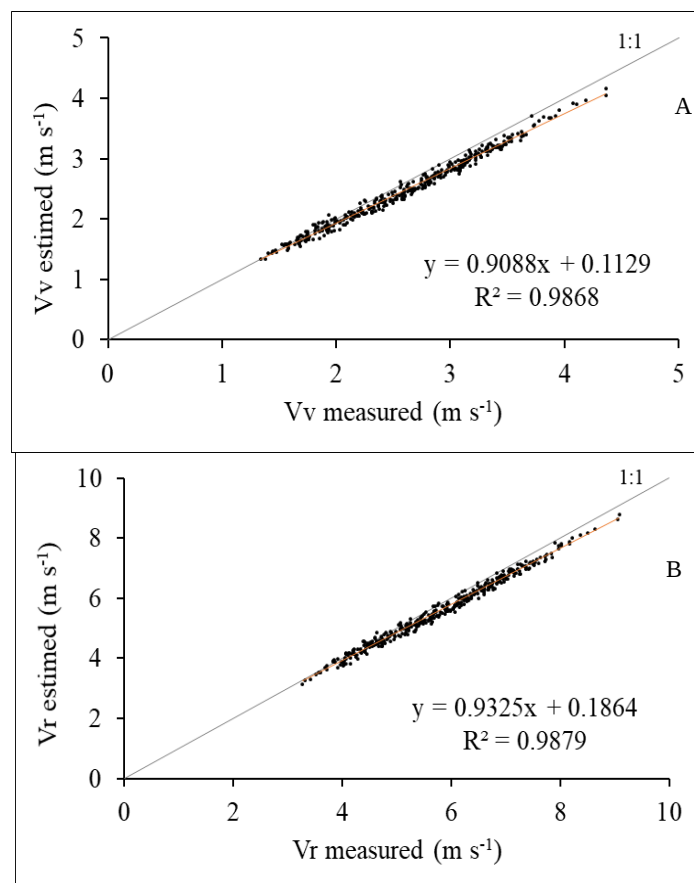


Figure 6. Correlation of Vv (A) and Correlation of Vr (B) between measured and estimated data for the second period.

The results obtained with the interpolation of the 14 stations allow the creation of thematic maps with the real power of interpolation for the sub-medium region of São Francisco, in other words, they allow the observation of the average wind speed and of wind gust for a radius of 250 Km in the Petrolina city. This way, although with less precision, was performed by Medeiros et al. (2005), who adjusted regression equations for the estimation of monthly and annual meteorological elements, making it possible to elaborate thematic maps of these elements for the Brazilian Northeast region.

Comparative studies between the application of semivariance and inverse interpolation of distance power are compromised because most of the researchers use the power of 2, although they are not ideal for such variables studied. One example is the study done by Luo et al. (2008) and Keskin et al. (2015) which reported that the IPD result was inadequate and attributed it to the weight at points where it is influenced by neighboring points, being this value weight 2 for the study of wind spatialization.

These data obtained for the wind velocity are an indispensable application for the estimation of the average velocities and bursts of the wind in regions of agricultural interest, contributing to the calculation of the more accurate ETo (Allen et al., 1998). It is even more noteworthy for agricultural production sensitive to abrupt meteorological changes and a temporary structure, such as the study by Bardin et al. (2012), who carried out the estimation of meteorological elements for areas of agricultural production in the state of São Paulo, and thus provides subsidies for better agricultural planning.

Conclusions

Os maiores valores diários da radiação solar global ocorreram em janeiro entre as 11 e 13h local.

The best power values of p obtained for Vv corresponded to 3.5; 3.7; 2.9; 4.2 and 3.0 for year, winter, spring, summer and autumn, respectively. In the same sequence of times, for Vr it was 3.4; 3.3; 2.9; 4.5 and 3.1.

The mean absolute error was the best measure of the inverse performance of the distance power for the spatialization of Vv and Vr. The mean error values were small when compared to the magnitude of the values and close to the instrumental error.

There is agreement between the measured and estimated values of Vv and Vr using the data of the second period, obtained with the cross-validation methodology, with R² values of 98.68% and 98.79%, respectively.

Observed values of ermid for Vv ranged from -7.5 to 4.9% and the average of 0.7%. For Vr, they ranged from -9.5 to 3.2% and the average of -1.2%.

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