Wind Characteristics and Assessment Using Meteorological Reanalysis Data over Selected Areas of South Algeria

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Abstract

The aim of this study is to evaluate the accuracy of two meteorological global reanalysis data sets in reproducing wind power regimes over three selected regions in south Algeria characterized by their high wind potential. The 3-hourly horizontal wind components at 10 m Above Ground Level (AGL) are extracted from the gridded reanalysis: ERA-interim data from the European Center for Medium Forecast (ECMWF) and the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis data at three geographical locations, namely Adrar (N ; W), In- Salah (N ; E) and HassiR'mel (N ; E). A study period spanning from January 2001 to December 2015 (15 years) was chosen. The extracted reanalysis data were compared on a daily basis with in-situ measurement data over the selected areas in terms of Bias, Root Mean Square Error (RMSE) and correlation coefficient (R). The wind rose frequency was also used for wind assessment. Globally, the ERA-interim and NCEP-NCAR reanalysis data were able to reproduce the wind regime over the selected regions despite an underestimation of the wind speed over all three regions. Average reanalysis daily wind speed ranges between -.. Overall, in the selected regions, better performance in reproducing the daily wind regime is achieved by ERA-interim reanalysis data with a minimum bias and a high correlation coefficient value of 0.85 in the region of In-Salah. Also, at the interannual time scale, the underestimation of wind speed is more significant, with a bias exceedingly high in periods of high wind activity. This period of high wind speed occurs in Spring (region of HassiR'mel) and extends to Summer (Adrar and In-Salah) with a predicted maximum monthly wind speed of during March-May at HassiR'mel and during May-July for Adrar and In-Salah.

Keywords: Wind assessment; Reanalysis data; ERA-interim; NCEP-NCAR; Algeria.

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1. Introduction

Wind power is a green source of energy that has become an important alternative to traditional power generated by fossil fuel combustion. Algeria is one of the North African countries where almost all of its electricity is produced from gas and fossil fuels. The Algerian government has embarked on a promising investment program in wind energy to install a wind capacity of 5 GW by 2030. Given the large area of Algeria and its geomorphological and climatic characteristics, the investment needs the identification of regions with high potential to deploy wind generators. In this context, several studies were carried out in Algeria to assess wind power energy, beginning with the work of Hammouche [1] who elaborated the first wind Atlas of Algeria in 1990. This work was updated in 2000 by Merzouk [2] Since then, several updates have been made to enhance the Algerian wind map, citing the work of Chellali et al. [3], Boudia et al. [4], Bencherif and Chikhaoui [5], Himri et al. [6] and DaaouNedjari et al. [7]. All these studies were based on observed surface wind data collected and provided by the Algerian Weather Service (ONM) at three-hourly and daily time scales. In recent years, several studies have been carried out worldwide to investigate the feasibility of global reanalysis data in the assessment and mapping of wind power energy. This global gridded data was gathered from a variety of sources, like satellites, buoys, radiosonde balloons, and observed data. All were integrated in a global forecast model with an assimilation scheme to reproduce a reanalysis of the global state of the atmosphere over a long period of time. In south Algeria, a comparative study of surface wind speed was undertaken by BARKA [8] using ERA-interim and measurement data over the regions of Hassi-R'mel and Ghardaia. This work was followed by a large-scale study using ERA-interim conducted over the whole country in 2019 by Boudia and Santos [9]. Also, an assessment and mapping of wind speed over Algeria was conducted by Fekih et al. [10] using the newly released global reanalysis data sets ECMWF-ERA5. However, these research works carried out remain insufficient, and there is still a need for more assessment of wind energy over Algeria in space and time using different sources of observational and reanalysis data to overcome the lack of knowledge related to the behavior of wind over Algeria, mainly in complex topographical areas and isolated arid regions. In this work, we investigate the accuracy of two widely used global reanalysis data sets: the NCEP-NCAR and the ERA-interim, in the assessment of wind energy resources over three selected sites in the south of Algeria during a period spanning from 2001 to 2015. For this purpose, we focused the analysis and discussion on three steps: wind direction, wind speed, and Weibull distribution analysis.

2. Data and Methods

In this study, we investigated the accuracy of two global reanalysis data sets in the assessment of the wind regime over three selected regions in south Algeria, namely Adrar, In-Salah, and HassiR'mel, as shown in Figure 1. The accuracy was determined by comparing reanalysis wind components at 10 m Above Ground Level (AGL) with direct synoptic wind measured at 10 m at selected sites. The two global reanalysis data sources considered in this study are: (1) the ERA-interim data [11] provided by the European Center for Medium Weather Forecast (ECMWF). The ERA-Interim data is available from 1979 onwards and is based on the ECMWF Integrated Forecast System, IFS (Cy31r2), 4-dimensional varational analysis (4D-Var) with a 12-h analysis window, and the assimilation of a wide range of surface and upper-air observational data from both in-situ and satellite instruments. Data are provided on a regular grid with a spatial resolution of approximately 80 km and 60 vertical pressure levels from the surface up to 0.1 hPa. (2) The second global reanalysis data is NCEP-NCAR R1 [12] which is a collaborative work between the National Oceanic and Atmospheric Administration (NOAA), National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). These data are produced by an advanced global analysis and forecasting system based on a 3D-Var data assimilation scheme starting from 1948 to the present. Data are available at a globally grid with 2.5 ° latitude by 2.5 ° longitude spatial resolution and 28 vertical pressure levels starting from the surface up 3hPa. The data are provided for a 4-day time period starting at 00 h UTC with a time frequency of six hours (06h). In order to assess the accuracy of the two reanalysis data in reproducing the wind regime and wind potential over Algeria. Surface wind fields at 10 m AGL namely the eastward u and the northward vcomponents, were extracted from the nearest grid point that matches the geographical locations of the three selected regions (Adrar, In-Salah, and HassiR'mel). Analysis was conducted for a study period spanning from January 1, 2001, to December 31, 2015 (15 years). using the widely used, freely open-source R software version 3.5.2 available at https://cran.r-project.org. Wind speed (V) and wind direction and (D) at every grid point were computed using the u and v components according to Equations 1 and 2.

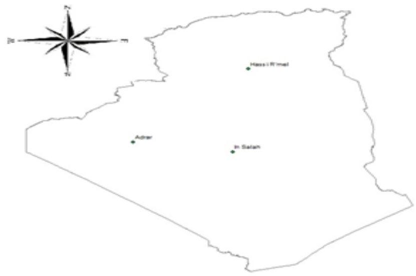

Figure 1: Domain study and windiest site locations. (By the authors)

$V = \sqrt{u^2 + v^2}$ (1)

$$D = \frac{180}{\pi}\arctan\left(\frac{u}{v}\right) + 180 \quad (2)$$

The daily synoptic surface wind speed and direction collected from the three locations mentioned in Table 1 were provided by the Algerian weather service (ONM) for the study period (2001–2015). The three sites are known for their high wind potential, as reported in [3], [4], and [7]. The observed wind data were used to validate the accuracy of the two reanalysis datasets, ERA-interim and NCEP-NCAR R1, on a daily basis. The observed sites and the study period are summarized in Table 1.

Table 1: Observational sites location and study period.

Location	Latitude(°)	Longitude (°)	Altitude (m)	Data frequency	Measurement period
Adrar	27.81	- 0.18	283	daily	2001-2015
In salah	27.25	2.51	269	daily	2001-2015
HassiR'mel	32.92	3.3	774	daily	2001-2015

To validate the accuracy of the two reanalysis datasets, annual surface reanalysis wind roses were plotted to investigate the prevailing wind regime over the three selected sites. Also, wind speed accuracy was determined using three statistical metrics calculated as follows [13-14]: The Mean Bias (MB), giving the tendency of reanalysis data (M_i) compared to measured values (O_i), for all the time series (N), it's given by:

$$MB = \frac{1}{N}\sum_{i=1}^{N} M_i - O_i \quad (3)$$

The Root Mean Square Error (RMSE) representing the deviation between reanalysis and measured values, it's given by:

$$RMSE = \left(\frac{\sum_{i=1}^{N}(M_i - O_i)^2}{N}\right)^{\frac{1}{2}} \quad (4)$$

The mean absolute percentage error shows the percentage deviation of predicted values compared to measured values. It is given by:

$$MAPE = \frac{100}{N}\left|\left(\frac{\sum_{i=1}^{N}(M_i - O_i)}{v}\right)\right| \quad (5)$$

We also calculated the correlation coefficient (R) varying between ± 1 giving the strength of the linear relation between reanalysis and measured data. The relationship is given by:

$$R = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{M_i - \overline{M}}{\sigma_M}\right)\left(\frac{O_i - \overline{O}}{\sigma_O}\right) (6)$$

σ_M and σ_O represent the standard deviation of reanalysis and measured wind speed, respectively. $\bar{M}$ and $\bar{O}$ are the average reanalysis and measured wind speeds, respectively.

The commonly used statistical Weibull function in the wind energy field was applied to characterize the wind speed frequency distribution and wind potential over the three selected regions. This method was reported to best fit the experimental data and was adopted in this study according to [3], [13]. This function is defined in Equation (7) as follows:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (7)$$

Where $f(v)$ is the probability of observing the wind speed v. The Weibull scale parameter C describes the magnitude of the wind speed in a desired location, and the shape parameter k describes the width of the data distribution. It is always greater than 1. Different methods have been provided for the estimation of the Weibull shape and scale parameters. In this study, we used the statistical Maximum Likelihood Method (MLM) to estimate the two Weibull parameters, (k) and (C) and the mean wind speed according to [14]. The two Weibull parameters are represented in equations 8 and 9.

$$k = \left[\frac{\sum_{i+1}^{n} v_i^k \ln(v_i)}{\sum_{i+1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right]^{-1} \quad (8)$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}} \quad (9)$$

Where n is the total number of wind speeds measured at the whole time period, and v_i is the wind speed at each time step i. The mean wind speed ($\bar{v}$) of the distribution is derived from the above two equations (10) and (11) and it is expressed as [17]:

$$\bar{v} = c.\Gamma(1 + \frac{1}{k}) \quad (10)$$

Γ: is the Gamma function expressed as:

$$\Gamma(X) = \left[\int_0^{\infty} t^{x-1} \exp(-t)\, dt\right] \quad (11)$$

3. Results and discussions

In this section, annual wind roses for observed and reanalysis data over the three selected regions for the whole period are presented in Figure 2. The wind rose is a diagram characterizing wind speed and its sector wise

distribution. Analysis shows the best agreement between observations and reanalysis in reproducing wind direction regimes, especially in the regions of In-Salah and Adrar (Figures. 2d-i) and slightly less agreement for the region of Hassi-R'mel (Figures.2a-c). Furthermore, the two reanalysis data sets predict in a satisfactory manner the wind flow coming from all directions in this region, the more frequent high predicted wind speeds greater than 06 m/s are underestimated for all directions, mainly from the north to north-east sector with a better performance of the ECMWF ERA-interim data sets, which are closer to the observations (Figure.2c). This underestimation in high wind speed is probably due to the site characteristics located in high topographical and accidental areas with the presence of obstacles. Such an underestimation was reported in [15] using the WRF model driven by NCEP-FNL reanalysis data as initial and boundary conditions. At the two sites of In-Salah and Adrar, the wind regime for observation and reanalysis is similar (see Figures.2d-i) with a main flow blowing north easterly. This finding was reported by DaaouNedjari et al.[7] over In-Salah. Also, the observed dominant north easterly wind sectors are well captured by the two reanalysis data over the two sites, with a clear underestimation of high wind speeds, which are less than 15 m/s compared with the observed high wind speeds reaching a maximum of 24 m/s at In-Salah and 26 m/s at Adrar. It is also noticeable that the ECMWF ERA-interim reanalysis performed better than the NCEP-NCAR reanalysis data sets in reproducing observed wind directions. Statistical metrics MBE, RMSE, MAPE and correlation coefficient (R) are computed from reanalysis and measured data of surface wind speed on a daily basis over the three selected sites, and results are presented in table 2. The best error scores are those highlighted in bold and characterized by lower errors and higher correlation. Results show that globally, the reanalysis surface wind speed is underestimated for both reanalysis datasets over the selected sites except the site of In-Salah which presents the closest overall error for ERA-interim data in terms of MBE (MBE=0.02 m/s). The surface wind underestimation was also reported using NCEP-FNL global analysis data over BordjBadjiMokhtar[15]. When comparing all statistical values, it is clearly seen that the ECMWF ERA-interim reanalysis wind speed shows the lower errors in terms of MBE, RMSE, MAPE and the higher correlations over the three selected regions. The best accuracy is identified at the site of In-Salah and scores are highlighted in bold as shown in table 2 (MBE=0.02 m/s , RMSE=1.48 m/s , MAPE=1%,R=0.85).

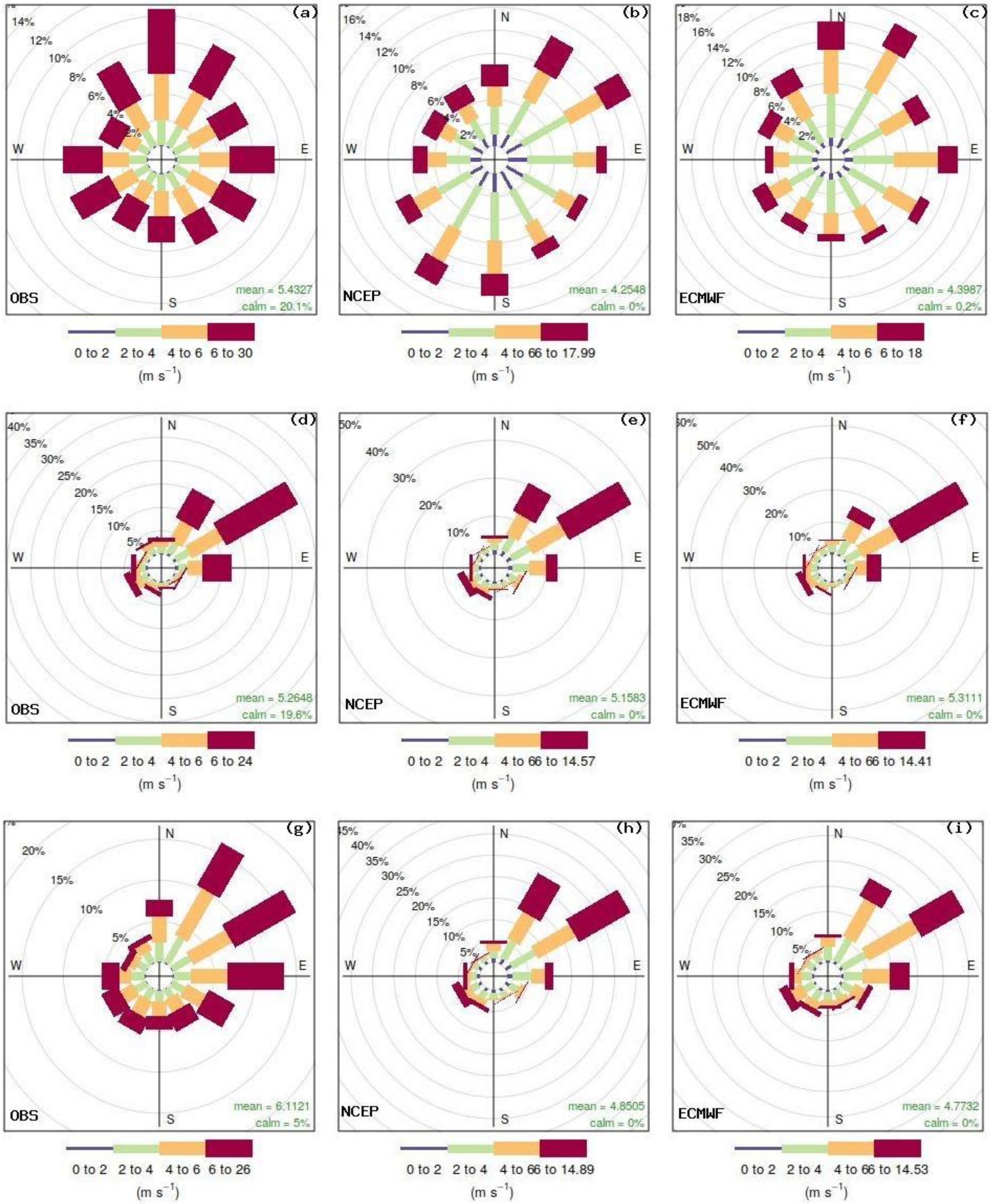

Figure 2: Wind rose diagrams for observation and reanalysis NCEP-NCAR, ECMWF ERA-Interim, (a-c) HassiR"mel,(d-f) In-Salah,(g-i) Adrar

Table 2 Statistical evaluation of the surface wind field over the selected sites

Parameter	Location	BIAS (m/s)	RMSE (m/s)	MAPE	Correlation (R)

		NCEP	ERA-I	NCEP	ERA-I	NCEP	ERA-I	NCEP	ERA-I
Wind speed at 10m	Adrar	-1.37	-1.37	2.18	1.83	21%	22%	0.64	0.8
	In Salah	-0.2	0.02	1.81	1.48	2%	1%	0.74	0.85
	Hassi R'mel	-1.27	-1.06	2.44	2.1	22%	19%	0.66	0.79

A deviation in the prediction of wind speed in the regions of Adrar and HassiRmel is identified compared with the region of In-Salah. The mean absolute percent error (MAPE) in wind speed ranges from a minimum of 1% at In-Salah to 22% at the regions of Adrar and HassiR'mel. The source of the discrepancy in the two regions is not clear, and it can be attributed to the frequency of lower wind speed values under 1ms⁄ and the frequency of missed data. The accuracy of the two reanalysis datasets was also evaluated using a scatter plot between surface observation and reanalysis wind speed on a daily basis. The results are presented in Figure 3. The cloud of points for the daily wind speed between observations and ECMWF ERA-interim reanalysis for the region of HassiR'mel is presented in Figure. 3a. The cloud of points is elongated along the line of best fit with a coefficient of determination equal to 0.62, meaning that 62% of the variance, which is the amount of information contained in the observation, is explained by ERA-interim. The best agreement is identified for wind speeds under 14% Low accuracy is identified in the prediction of high wind speeds. An underestimation in wind speed is also identified with a bias of 1.06ms⁄ with a deviation error in MAPE of around 19%. Furthermore, over the same region, figure 3.b depicts the correlation between observed and NCEP-NCAR reanalysis daily wind speeds. The cloud of points is elongated along the line of best fit with less accuracy compared to the case of the ECMWF ERA-interim. The correlation is low and equals 0.44, meaning that NCEP-NCAR data explains only 44% of the information contained in observations. The error in the prediction of wind speed reaches a MAPE value of 22%. The wind speed is underestimated with a bias of 1.27ms⁄. Figures.3.c,d show the wind speed density plot between observations and reanalysis over In-Salah. The cloud of points is symmetrically elongated on either side of the line of the best fit (Figure 3c) with the lowest bias for ERA-interim data equal to 0.02ms⁄ and an error in MAPE equal to 1%. The correlation of determination reaches a value of 0.72, meaning that ERA-interim explains 72% of the variance in daily wind speed. Furthermore, a lower accuracy in wind speed in the case of the NCEP-NCAR reanalysis (Figure.3d) is identified with an underestimation of -0.2 m ⁄s.The MAPE error in predicting wind speed reaches a value of 2%. The scattering of cloud points on either side of the line of the best fit is large compared to the ERA-interim case, with only 55% of the variance explained by NCEP-NCAR reanalysis data. Similarly to the two regions of HassiR'mel and In-Salah, the region of Adrar exhibits the same behavior for the two reanalysis data ends (ERA-interim) end (NCEP-NCAR) as reported respectively in Figure.3e and Figure.3f. The cloud of points is elongated along the line of best fit for ECMWF reanalysis data with the best accuracy compared to NCEP-NCAR reanalysis data showing a cloud of points scattered on either side of the line of best fit. According to table 2, wind speed is underestimated for the two cases with a bias of −1.37ms⁄ and a MAPE error around 21%. The coefficient of determination (R2) ranges between 0.41 for NCEP-NCAR and 0.63 for ECMWF reanalysis, meaning that 63% of observed wind speed data were predicted by ECMWF ERA-interim reanalysis with the best accuracy in comparison to NCEP-NCAR reanalysis data, which explains only 41% of the variance in wind speed. Overall, the low RMSE values over the three selected regions confirm the best performance of the ECMWF ERA-interim compared to NCEP-NCAR reanalysis daily wind speed data. This finding was also reported in an earlier study conducted in Portugal [16]. Furthermore, the best accuracy was registered in the region of In-Salah showing the lowest RMSE of 1.48ms⁄ in predicting wind speed using ECMWF ERA-interim.

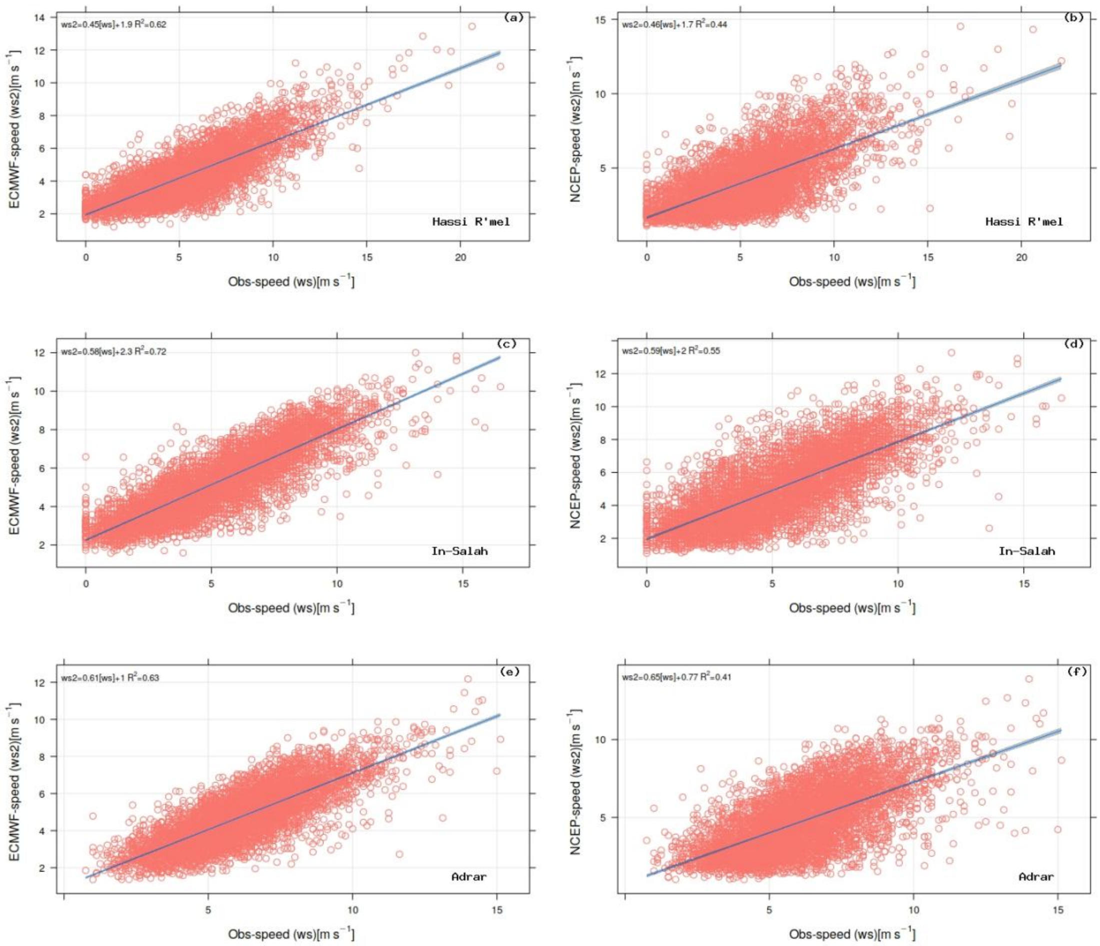

Figure 3: Wind speed scatter plot for observed an reanalysis NCEP-NCAR and ECMWF ERA-interim, (a,b) Adrar, (c,d) In-Salah, (e,f) Hassi R'mel

In addition to statistical analysis described above, wind energy was investigated using the Weibull probability function which represents wind speed distribution. For this purpose, the values of c (scale parameter), and k (the shape parameter) along with the estimated mean wind speed are represented in table 3. The results show that observed mean wind speed was underestimated by reanalysis wind speed which varies between $4.26 - 5.30\,m/s$.The wind speed underestimation reaches a value of −1.34ms⁄ at Adrar and 1.17ms⁄ at Hassi R'mel. These errors significantly affect the wind potential which is closely related to the cube of the wind speed. In the same context, large discrepancies were identified in the estimation of the shape parameter in both reanalysis which affect the wind power assessment.

Table 3: Weibull parameters and mean wind speed

	Observation			NCEP			ERA-I		
Location	K	C	$\bar{v}$	K	C	$\bar{v}$	K	C	$\bar{v}$
		(ms-1)	(ms-1)		(ms-1)	(ms-1)		(ms-1)	(ms-1)
Adrar	2.19	6.9	6.11	2.25	5.49	4.85	2.78	5.36	4.77
In Salah	1.38	5.82	5.26	2.28	5.83	5.16	2.67	5.98	5.31
Hassi R'mel	1.35	5.98	5.43	1.96	4.82	4.26	2.37	4.97	4.39

4. Interannual variability of wind speed

Figure 4 depicts the interannual variation of monthly wind speed for the NCEP-NCAR and ERA-Interim reanalysis for the study period. Analysis shows clearly the significant underestimation of the reanalyzed wind speed for all years and over all locations, mainly over HassiR'mel and Adrar. This finding is also reported in [10] using ERA5 data. Despite this underestimation, the interannual variability of wind speed is satisfactorily reproduced by the two reanalysis data sets. Analysis of the wind speed for the region of HassiR'mel (Figures. 4a, b, and c) shows that the observed wind speed pattern (Figure. 4a) agrees well with the two reanalysis data sets, namely the occurrence of high and low windy periods, which were well reproduced (Figures .4b,c). The high wind speed period starts from February to June as a common characteristic in arid areas, and the monthly maximum wind speed occurs during the spring (March to May) [17–19]. The maximum wind speed reaches a value of $8\,\mathrm{m/s}$ for the observation and $06\,\mathrm{m/s}$ for the reanalysis.

The low-windy period starts in July and extends to January. In this period, both reanalysis data show poor performance in accurately reproducing the interannual variability of wind speed. This behavior cannot be explained and is probably due to site characteristics and measurements. For the region of In-Salah (Figures 4d, e, and f), interannual variability in monthly wind speed distribution is satisfactorily reproduced by reanalysis data despite differences in predicting high wind speed for the two periods 2002–2004 and 2011–2013, which are underestimated by the NCEP-NCAR and ERA-interim reanalysis data. The high wind speed period starts from

February to August, and the monthly maximum wind speed occurs during the summer (May to July), with a wind speed reaching 8 m/s for both observations and reanalysis. The low-windy period starts in September and extends to January. The minimum observed wind speed reaches a value of 2 m/s and it's overestimated by both reanalysis data, which records a minimum value of 3 m/s during winter period. Analysis of the wind speed for the region of Adrar (Figures 4g, h, and i) shows differences between the observed and reanalyzed wind speed patterns at the interannual scale. A significant underestimation of monthly wind speed is identified with a bias exceeding 2 m/s. According to figure 4g, the observed monthly high wind speed reaches a value of 8 m/s and occurs throughout the year, mainly for the period between 2008 and 2010. This behavior is not reproduced by reanalysis data (Figures 4.h,i). The reanalyzed monthly high wind speed reaches a value of 6 m/s and occurs between February and August. The low windy period starts in September and extends to January. The minimum observed wind speed is under a value of 4 m/s and is underestimated by both reanalysis data, which records a minimum value under 3 m/s during winter. Overall, the interannual variability of wind speed is well reproduced in the region of In-Salah with the same performance by two reanalysis data sets (ERA-interim and NCEP-NCAR).

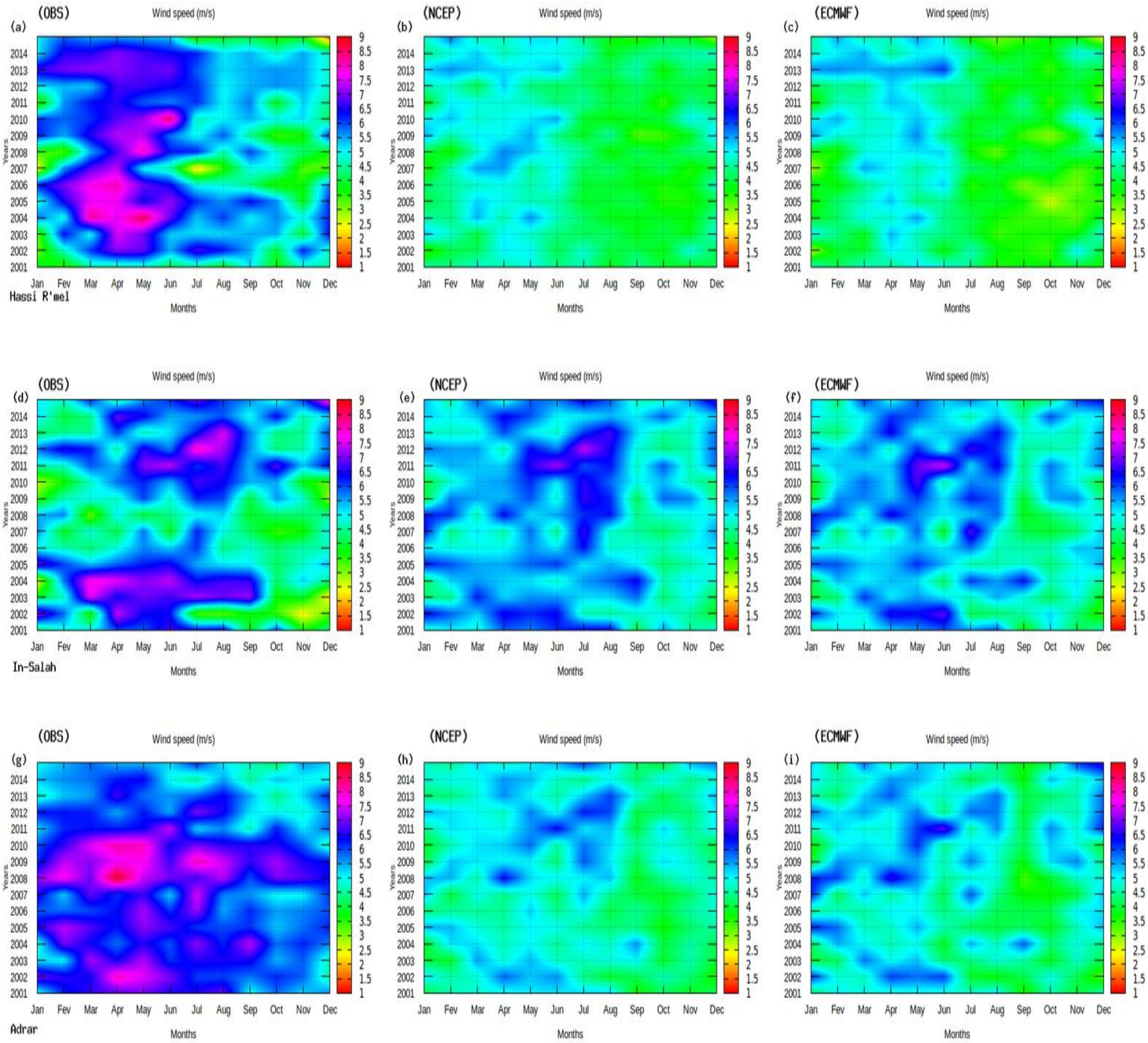

Figure 4: Interannual variability of wind speed for observed and reanalyzed NCEP-NCAR, ECMWF ERA-Interim, (a-c) Hassi R'mel,(d-f) In-Salah,(g-i) Adrar

5 Conclusions

The accuracy of two widely used global reanalysis data sets in the assessment of wind energy is investigated in three selected regions of south Algeria. 10-m wind fields were extracted from reanalysis (ECMWF ERA-interim and NCEP-NCAR) databases and compared with observational data on a daily basis for a period of 15 years (2001–2015). Comparison was performed using statistical metrics (Bias, RMSE, and correlation coefficient). The results show that the best agreement is found between observations and reanalysis data in the reproduction of wind direction regimes over the selected areas, mainly at the two sites of Adrar and In-Salah with prevailing wind directions coming from the north-east for all three sites. Statistical analysis shows that daily surface wind speed is underestimated by reanalysis data over the selected regions with the best performance of the ECMWF ERA-interim data. The minimum bias of 0.85 and high wind speed correlation values recorded in the region of IN-Salah. Moreover, at the interannual time scale, the underestimation of wind speed by the two reanalysis data sets is more significant for all studied locations. The bias exceeds a value during periods of high wind activity. High wind speed occurs in spring (region of Hassi R'mel) and extends to summer (region of Adrar and In-Salah), with a predicted maximum monthly wind speed of during March-May at Hassi R'mel and in the period of May-July for Adrar and In-Salah. Despite the underestimation, wind speed behavior is well captured by the two reanalysis data sets, ERA-interim and NCEP-NCAR for all years and all locations, namely in the region of In-Salah.

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References

[1] R. Hammouche, "Atlas Vent de l'Algerie." Office National de la Meteorologie, 1990.

[2] N. K. Merzouk, "Wind energy potential of Algeria," Renewable Energy, vol. 21, no. 3–4, pp. 553–562, 2000.

[3] F. Chellali, A. Khellaf, A. Belouchrani, and A. Recioui, "A contribution in the actualization of wind map of Algeria," Renewable and Sustainable Energy Reviews, vol. 15, no. 2, pp. 993–1002, 2011.

[4] S. M. Boudia, A. Benmansour, and M. A. Tabet Hellal, "Wind resource assessment in Algeria," Sustainable Cities and Society, vol. 22, pp. 171–183, 2016.

[5] M. Bencherif and A. Chikhaoui, "Evaluation of wind energy generation and site pairing of wind turbines in Algeria," Wind Engineering, vol. 38, no. 1, pp. 23–37, 2014.

[6] Y. Himri, S. Rehman, S. Himri, K. Mohammadi, B. Sahin, and A. S. Malik, "Investigation of wind resources in Timimoun region, Algeria," Wind Engineering, vol. 40, no. 3, pp. 250–260, 2016.

[7] H. Daaou Nedjari, S. K. Haddouche, A. Balehouane, and O. Guerri, "Optimal windy sites in Algeria: Potential and perspectives," Energy, vol. 147, pp. 1240–1255, 2018.

[8] I. BARKA, D. BARKA, and F. Abdellali, "Etude comparative des données du vent observées et les données ré-analysées ECMWF à Hassi R'mel et Gharda⌧a," Université de Ouargla, 2017.

[9] S. M. Boudia and J. A. Santos, "Assessment of large-scale wind resource features in Algeria," Energy, no. xxxx, p. 116299, 2019.

[10] A. Fekih, M. Abdelouahab, and Y. Marif, "Evaluation of wind resource and mapping during 2009–2018 based on ERA5 reanalysis data: a case study over Algeria," International Journal of Energy and Environmental Engineering, pp. 1–20, 2022.

[11] D. P. Dee, S. M. Uppala, A. J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M. A. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A. C. M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A. J. Geer, L. Haimberger, S. B. Healy, H. Hersbach, E. V. Hólm, L. Isaksen, P. Kållberg, M. Köhler, M. Matricardi, A. P. Mcnally, B. M. Monge-Sanz, J. J. Morcrette, B. K. Park, C. Peubey, P. de Rosnay, C. Tavolato, J. N. Thépaut, and F. Vitart, "The ERA-Interim reanalysis: Configuration and performance of the data assimilation system," Quarterly Journal of the Royal Meteorological Society, vol. 137, no. 656, pp. 553–597, 2011.

[12] E. Kalnay, M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, "The NCEP/NCAR 40-year reanalysis project," Bulletin of the American Meteorological Society, vol. 77, no. 3. pp. 437–471, 1996.

[13] Y. Himri, S. Himri, and A. B. Stambouli, "Wind power resource in the south-western region of Algeria," Renewable and Sustainable Energy Reviews, vol. 14, no. 1, pp. 554–556, 2010.

[14] K. S. R. Murthy and O. P. Rahi, "A comprehensive review of wind resource assessment," Renewable and Sustainable Energy Reviews. 2017.

[15] A. Fekih and A. Mohamed, "Evaluation of the WRF model on simulating the vertical structure and diurnal cycle of the atmospheric boundary layer over Bordj Badji Mokhtar (southwestern Algeria)," Journal of King Saud University - Science, 2017.

[16] D. Carvalho, A. Rocha, M. Gómez-Gesteira, and C. Santos, "A sensitivity study of the WRF model in wind simulation for an area of high wind energy," Environmental Modelling & Software, vol. 33, pp. 23–34, 2012.

[17] S. M. Boudia, A. Benmansour, and M. A. Tabet Hellal, "Wind Energy Resource Assessment at Tindouf Region, Extreme Southwest of Algeria," Applied Mechanics and Materials, vol. 541–542, pp. 972–976, 2014.

[18] S. Boudia, A. Benmansour, N. Ghellai, M. Benmedjahed, and M. Tabet Hellal, "Monthly and seasonal assessment of wind energy potential at Msila region-Algerian highlands," in

First International Conference on Renewable Energies and Nanotechnology impact on Medicine and Ecology (ICREN-01/2013), 2013.

[19] M. Benmedjahed, N. Ghellai, Z. Bouzid, and A. Chiali, “Temporal assessment of wind energy resource in ‘Adrar’(south of Algeria); calculation and modeling of wind turbine noise,” in <i>2nd International Congress on Energy Efficiency and Energy Related Materials (ENEFM2014)</i>, 2015, pp. 33–42.