August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Validation of the ERA5 reanalysis surface winds over Ethiopia

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SUMMARY:
This study focuses on validating the ERA5 reanalysis surface wind climatology in Ethiopia. The hourly wind speed and direction data from the ECMWF's latest reanalysis dataset, ERA5, are compared with 10 min in-situ wind observations obtained from 17 wind mast locations across Ethiopia. The analysis includes examining the variability of wind patterns in terms of the annual cycle and wind probability distribution. The behavior of wind speed throughout the year and on an hourly basis is first presented. The ERA5 reanalysis surface winds successfully reproduce both the monthly and hourly wind profiles across all locations. Correlation coefficients higher than 0.8 are observed for the majority of stations (14 out of 17), while a few stations exhibit correlations between 0.7 and 0.8. Skill scores indicate a significant level of agreement between ERA5 and observed wind speed, with values ranging from the highest score of 0.98 at Gode1 to the lowest score of 0.38 at Sela Dingay. Overall, the results demonstrate that the ERA5 dataset realistically represents the wind climatology in Ethiopia.

Keywords: ERA5, reanalysis datasets, surface wind, Ethiopia

1. INTRODUCTION

Accurate assessment of climatological wind is crucial for a wide range of applications such as meteorology, wind energy, air pollution, navigation, and building design. A robust resource assessment necessitates a dense network of measurement stations at higher temporal resolutions. However, high-quality long-term wind data are scarce over Ethiopia Asress et al., 2013; Fazzini et al., 2015. Therefore regional-scale wind resources assessment is possible through climate modeling and the use of reanalysis. Recent advances and improvements in reanalysis products have made their use in wind energy resource assessment possible. However, reanalysis data sets must be first validated in order to be used for wind resource assessment. ERA5 reanalysis data of the European Center of Medium Range Weather Forecast (ECMWF) has a higher temporal and spatial resolution compared to other global reanalysis datasets. Several studies Campos et al., 2022; Olauson, 2018 have demonstrated the capability of ERA5 to accurately represent wind climatology in different countries and regions. This paper sets out to describe the characteristics of wind over Ethiopia and evaluate to what extent ERA5 surface wind reproduces spatial and temporal variability of the observed wind over Ethiopia.

2. DATA AND METHODS

2.1. Study area and data

Ethiopia is located in the Horn of Africa between 33.00°- 48.00° East and 3.41°-14.89° North. The total area of the country is 1,104,300 sq. km of which 7,730 sq. km is water. Ethiopia is a country known for its complex topography. As a result, the climate of Ethiopia is as complex as the topography. For the purpose of validation of the latest ERA5 10m surface winds, a data repository for measurements from 17 wind masts in Ethiopia was used ESMAP, 2022. The wind measurement campaign took place from 2019 to 2021.

2.2. Methodology

Statistical tests were conducted to assess bias, root mean square error (RMSE), and Pearson's correlation coefficient (R) for both wind speed and wind direction using relevant equations. Additionally, the performance of the ERA5 reanalysis wind was evaluated using the Weibull Probability Distribution (WPD) function. WPD testing examined the agreement between the reanalysis outputs and observations, disregarding the temporal variability of the wind resource. The Weibull probability density function f(V) was derived to facilitate the analysis.

$$f(V) = (\frac{k}{c}).(\frac{V}{c})^{(k-1)}.e^{-(\frac{V}{c})^k} \tag{1}$$

Where V(ms^{-1}) is the wind speed, c(ms^{-1}) is the Weibull scale factor, which could be related to the average wind speed through the dimensionless shape factor, k, which describes the distribution of the wind speeds Assowe Dabar et al., 2019. To estimate the Weibull parameters k and c, the relationships based on the most widely used maximum likelihood method Baseer, Meyer, Alam, et al., 2015; Baseer, Meyer, Rehman, et al., 2017; Chang et al., 2003 are given below.

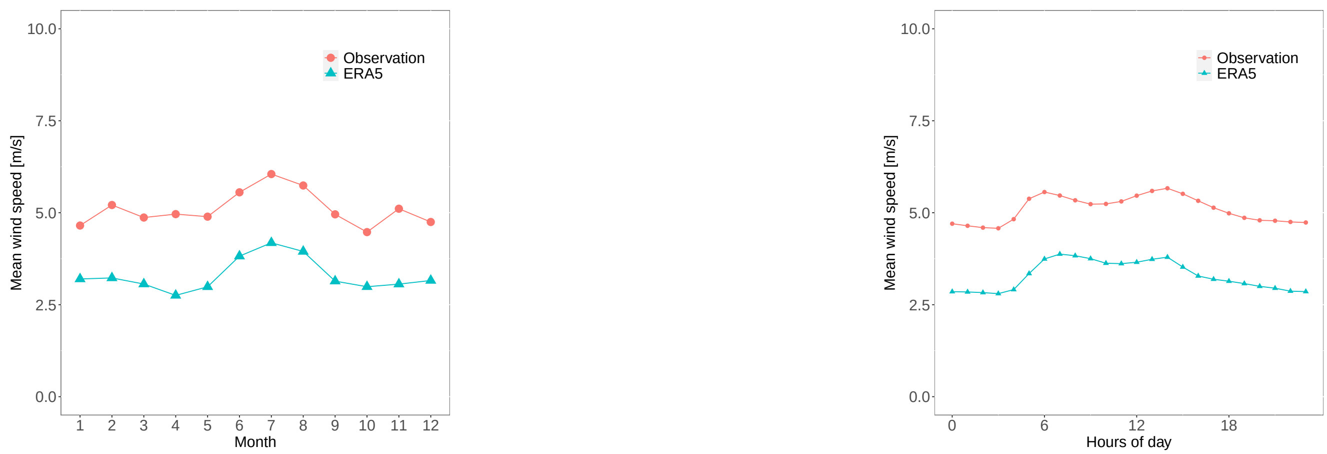
$$k = (\frac{\sum_{i=1}^{n} v_i^k ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n})^{-1} \tag{2}$$

$$c = (\frac{\sum_{i=1}^{n} v_i^k}{n})^{\frac{-1}{k}} \tag{3}$$

Where Vi is the wind speed and n is the number of non-zero wind speeds. The evaluation of the WPD was based on the amount of area overlap between the simulated and observed wind field developed by Perkins et al., 2013 and used for wind resource evaluation by Molina et al., 2021. The score value of the overlap is given by:

$$Score = \sum_{i=1}^{n} min(z_{mi}, z_{oi}) \tag{4}$$

Where n is the number of bins used to calculate the frequency and Zm and Zo are the frequency for model data and observations, respectively. The minimum point between the mode and observation forms the common area between the distribution in evaluation.



(a) Monthly wind speed

(b) Hourly wind speed

Figure 1. The overall 10m monthly mean wind speed of observations from wind mast locations and their corresponding ERA5 reanalysis datasets.

3. RESULTS AND DISCUSSIONS

3.1. Statistical comparison of ERA5 against observations

An overview of the overall mean annual cycle of wind speed, computed on a monthly and hourly timescale is presented in Figure 1. The in-situ observations show maximum wind speed in summer and minimum in autumn and spring. The noticeable property of the hourly wind profile is that it reveals two windy peak hours; first in the morning at 06:00 and second at 14:00. The summary of statistical test results is presented in Table 1 1. The ERA5 monthly mean wind speed correlate strongly over all the wind mast stations analyzed. Most of the stations (14 out of 17) have correlation coefficients higher than 0.8. A few stations have correlations between 0.7 and 0.8. Over most of the regions, a large variability of RMSE bias is observed. The RMSE values range between 3.5 ms^{-1} and 0.37 ms^{-1}, indicating variations in the accuracy of the wind speed estimations. Additionally, the bias values range between 3.26 ms^{-1} and -0.14 ms^{-1}.

3.2. The Weibull probability distribution and area overlap

Qualitative assessment of the observed annual histogram plot suggests that all stations exhibit a unimodal distribution, indicating a good fit with the Weibull probability distribution (WPD). The WPD performs well in reconstructing the observed wind speed distribution. Subsequently, a comparison of the ERA5 distribution is conducted by evaluating the area overlap between the Weibull distribution fits. The skill scores, indicating the area overlap between ERA5 and observed wind speed, are provided in Table 1 and demonstrate high agreement between the two datasets.

4. CONCLUSION

This study validates the ERA5 reanalysis surface wind climatology over Ethiopia using in-situ wind observations from multiple mast locations. Results show that ERA5 accurately represents the spatial and temporal wind variability. Strong correlations were observed between ERA5 and observed wind speeds at most stations. The Weibull Probability Distribution effectively reconstructed the observed wind speed distribution. These findings support the suitability of ERA5 for wind resource assessment in Ethiopia.

Table 1. Summary of statistical results and overlap of wind speed from wind mast stations and ERA5. Wspd: mean wind speed (ms^{-1}). Std: standard deviation.

Station names	Lat	Lon	Elev	Observation		ERA5		R	RMSE	Bias	Overlap
			(m)	Wspd	Std	Wspd	Std				
Adigala	42.2	10.4	764	5.43	0.88	4.76	0.84	0.77	0.87	0.67	0.87
Asosa	34.7	9.9	1454	2.37	0.38	1.45	0.28	0.76	0.95	0.92	0.67
Aysha_1	42.5	10.8	660	7.09	1.7	5.19	1.05	0.9	2.08	1.9	0.71
Aysha_2	42.6	10.8	740	7.59	1.82	5.19	1.05	0.86	2.61	2.4	0.64
Deday	41.6	11.9	470	4.51	0.54	2.35	0.19	0.77	2.2	2.16	0.48
Dire Dawa_1	42.0	9.7	1002	4.27	1.54	2.6	0.79	0.93	1.86	1.67	0.68
Dire Dawa_2	41.9	9.8	1029	4.57	1.07	2.6	0.79	0.94	2.01	1.97	0.57
Gode_1	43.3	5.6	495	5.47	2.36	5.61	2.27	0.99	0.39	-0.14	0.97
Gode_2	43.4	5.5	520	5.5	2.38	5.61	2.27	0.99	0.37	-0.11	0.98
Kebribeyah	43.3	8.9	1615	6.24	1.29	3.04	0.94	0.88	3.26	3.2	0.42
May Mekden	39.6	13.6	2420	5.38	1.47	2.12	0.26	0.71	3.49	3.26	0.4
Mega	37.8	4.3	1095	4.77	1.72	3.52	0.67	0.98	1.63	1.26	0.71
Sela Dingay	39.6	9.9	2930	4.56	1.11	1.73	0.21	0.61	2.98	2.83	0.35
Sure	41.6	9.6	1130	3.58	0.47	2.00	0.39	0.9	1.59	1.58	0.53
Tulu Guled_1	42.7	9.7	1900	5.34	1.42	3.06	0.64	0.89	2.45	2.29	0.54
Tulu Guled_2	42.8	9.7	1920	5.37	1.09	3.06	0.64	0.86	2.4	2.32	0.51
Ziway	38.7	7.9	1650	4.63	0.66	2.13	0.41	0.87	2.53	2.5	0.38

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