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Evaluating the Performance of Diurnal Wind Speed Models for Some Selected Tropical Stations in South West Zone, Nigeria

Akinnubi R.T and Adeniyi M.O.
[1]Department of Physics, Anchor University Lagos, Nigeria.
[2]Department of Physics, University of Ibadan, Nigeria

***Corresponding author:**
E-mail: : rufus782000@yahoo.com;

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ABSTRACT

Background: Wind speed diurnal patterns are required for monitoring the Global Energy Budget and predicting climate change in humid tropical areas.
Objectives: This article validated three distinct diurnal wind speed models (Ephrath, Gregory, and Harmonic Analysis) for estimating hourly wind speed from daily maximum, daily minimum, and daily mean wind speed.
Methods: The performance of three different diurnal wind speed models is validated using Surface Layer observations from the Nigeria Micrometeorological Experimental Site (NIMEX) for two locations.
Results: The overall performance of the Gregory and Harmonic Analysis models revealed a large deviation from the measured data, whereas Mean Bias Error (MBE) and Root Mean Square Error (RMSE) values were found to be low for wet days (-0.10 ms^{-1} and 0.55 ms^{-1}, respectively) for the Ibadan site and Ile-Ife site (-0.20 ms^{-1} and 0.74 ms^{-1}, respectively) for the Ephrath Sinusoidal Model. On dry days, the Ephrath Sinusoidal Model MBE and RMSE values for the Ibadan location were -0.16 ms^{-1} and 0.64 ms^{-1}, respectively, while they were -0.06 ms^{-1} and 0.76 ms^{-1} for the Ile-Ife site. The findings also demonstrated that the performance of the Ephrath Sinusoidal Model at the Ibadan location was better on rainy days than it was on dry days.
Conclusion: The Ephrath Sinusoidal Model generated forecast results that are appropriate to the region based on the performance.

Keywords: Wind Speed, Energy, Resource, Synoptic, Humid

INTRODUCTION

The wind is a critical parameter in wind erosion modeling, evapotranspiration computation, and renewable energy resource characterization. As is widely known, wind transports heat and efficiently mixes the soil-atmospheric boundary layer. Because wind is largely constituted of turbulent flow with random variation, it is typically very changeable in terms of speed and direction (Sebastian *et al*., 2021; Kunal *et al*., 2020; Saito *et al*., 2006; Ephrath *et al*., 1996; Elmore and Gallagher, 2009; Kennedy, 2003; Shamshad *et al*., 2005). However, it is critical to incorporate a range of air resource-related parameters, including wind, into integrated resource management planning to conduct critical study on the diurnal patterns of wind speed fluctuations over 24-hours in humid tropical regions (Sebastian *et al*., 2021; Kunal *et al*., 2020: Hagninou *et al*., 2019; Billington,1996; Beyer and Nottebaum., 1995; Vining and Allen, 1993). Because the majority of parameterization techniques for energy balance equation components require continuous wind speed inputs, even if only daily average data are provided, continuous diurnal changes in wind speed must be simulated.

Diurnal fluctuations in meteorological parameters are critical for our knowledge of weather and climate systems. Numerous studies have been conducted on the diurnal fluctuations of global or local meteorological factors (e.g., precipitation and surface winds).

However, due to the scarcity of available observational data, early investigations of these diurnal oscillations were limited to tropical regions. Cloud cover, cloud crest brightness temperature and water vapor were utilized to explore diurnal fluctuations in convective activity using infrared satellite data (He *et al*., 2013; Bianco *et al*., 2016; Yang and Slingo, 2001; Nesbitt and Zipser, 2003; Bowman *et al*., 2005; Zuidema, 2003).

The diurnal patterns of wind speed have been thoroughly studied, and several models have been devised (He *et al*., 2013; Bianco *et al*., 2016Castellanos and Ramesar, 2006; Billington *et al*., 1996; Castro and Allan, 1996). The majority of these models estimate hourly wind speeds for several days using statistical, numerical, or physical methods. Sine waves are widely used to represent daily wind speed changes (Frank *et al*.,2020; He *et al*., 2013; Bianco et al., 2016; Gregory, *et al*., 1994; 1996; Saito *et al*., 2006; Ephrath *et al*., 1996). Except for the wet tropical area, the majority of the models have been validated in other climatic zones throughout the world (Frank *et al*.,2020: Saito *et al*., 2006; Ephrath *et al*., 1996)

Due to a scarcity of diurnal meteorological data on wind speed, analyzing wind resources in this region is difficult. The purpose of this research is to assess the performance of previously developed diurnal wind speed models to determine their suitability for this climate scenario. Due to the high degree of variability in wind speed and direction, the diurnal effect of local wind on several other atmospheric variables will be explored using synoptic data from the Nigeria Micrometeorological Experimental site.

2.0 MATERIAL AND METHODS

The observational data sets used in this investigation were extracted from NIMEX data.

2.1 EXPERIMENTAL SITES

Nigeria Micrometeorological Experiment (NIMEX) (Jegede *et al*., 2004) was conducted at Ile Ife (Latitude 7°33′N and longitude 4°33′E) in Nigeria during the transition period from dry to wet season (Fig. 1). The period of intensive observation was from February 19th through to March 9th [day of the year (DOY) 55 through DOY 68, using Julian days notation] in 2004. This site is located in the humid equatorial region of West Africa and the climatic region is Aw class according to Köppen classification (Akinnubi and Adeniyi, 2019: Essenwanger, 2001). This site is at an altitude of 288 m above sea level and its vegetation can be characterized as fallow bushland. The ground surface of the site is flat and homogenous. The soil is loamy sand and it is at its permanent wilting condition at the beginning of the experiment (Akinnubi and Adeniyi, 2019; Jegede *et al*. 2004; Mauder *et al*. 2006). The maximum and minimum air temperatures during the period of the experiment were 46.33 and 20.04 °C, respectively and the mean annual rainfall amount is 1225 mm (Akinnubi and Adeniyi, 2019; Otunla and Oladiran 2013). Another Nigeria Micrometeorological Experiment (NIMEX:) was carried out on the experiment field of the lower atmospheric Physics unit at the University of Ibadan in Ibadan, Nigeria (70 25' N, 30 53' E). In 2007, the intensive observation period lasted from February 22nd to March 31st (DOY 54 to DOY 90). (Fig. 2). The period corresponds to the shift from dry to wet conditions. The place is approximately 78 kilometres from Ile-Ife. The location consists of 850 m^2 of flat ground at an elevation of 220 m above sea level. At 0.05 m deep, the soil is loamy sand with a bulk density of 1600 kgm^{-3}. During the measuring period, the target area's ground surface was bare. The topography of the landscape surrounding the site can be described as undulating low land with a few high points visible from the location (Otunla and Oladiran, 2013). During the experiment, the recorded wind speed ranged from 0.04 to 2.93 ms^{-1}. According to Foken (2003), a simple visual test was employed daily to verify te validity of the basic meteorology variables (slow response) (Akinnubi and Adeniyi, 2019; Jegede *et al*., 2004; Mauder *et al*., 2006).

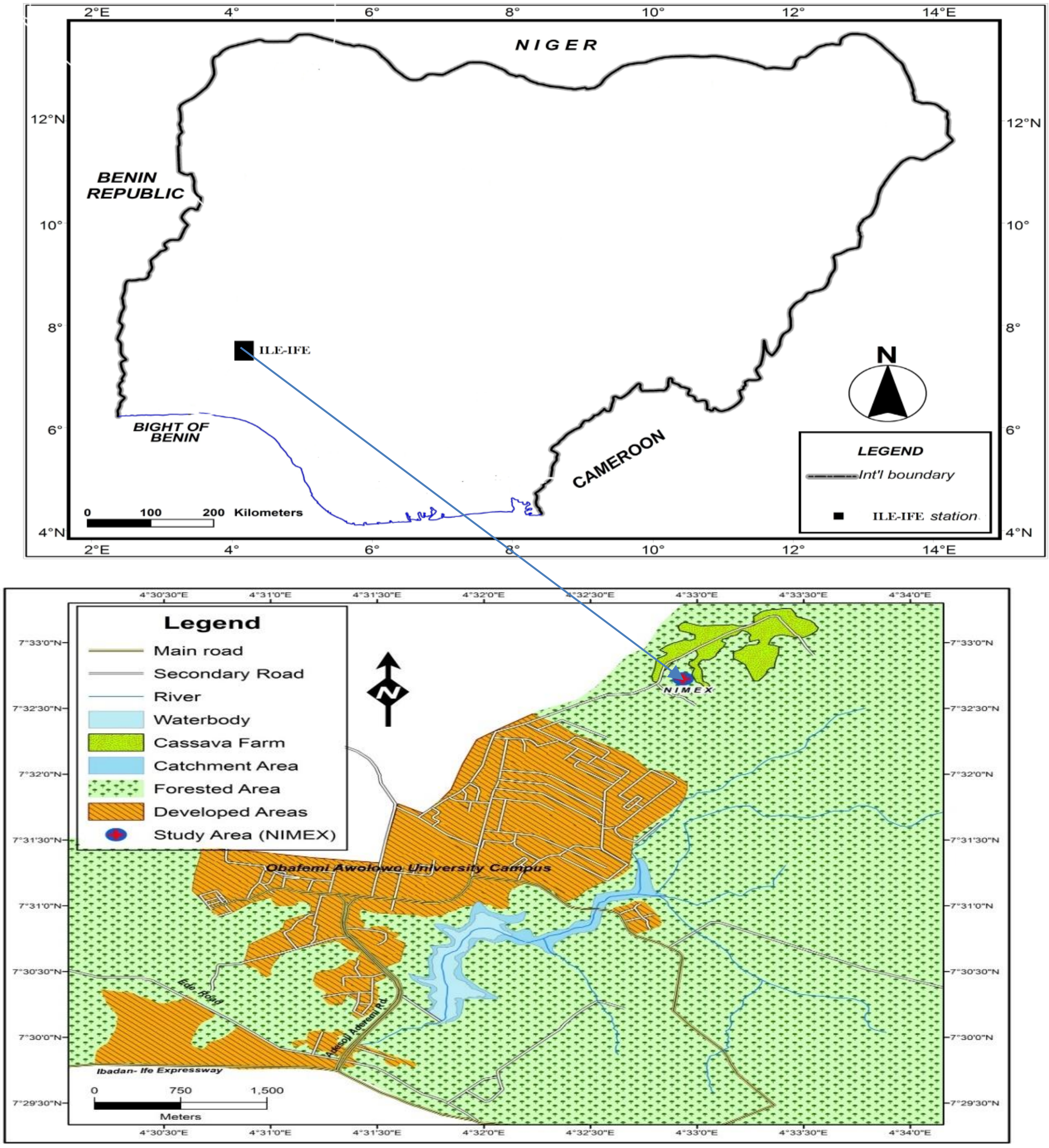

Figure 1: Sketch showing the position of the measurement site (Ile-Ife) in Nigeria

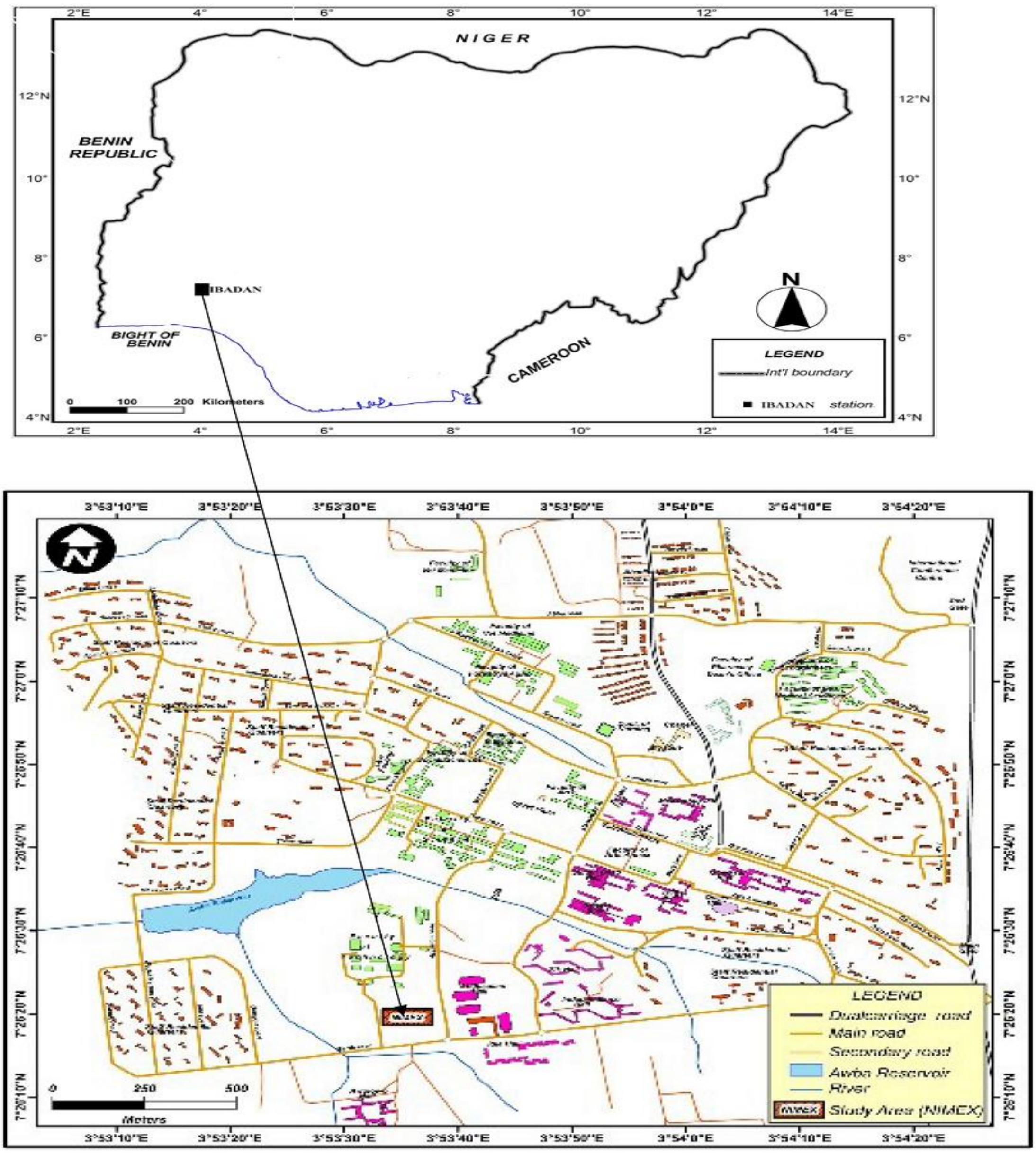

Figure 2: Sketch showing the position of the measurement site (Ibadan site) in Nigeria.

2.1 Diurnal Wind speed Models.

2.1.1 Harmonic Analysis Technique (HAT): A broad overview of Harmonic analysis has been reported by many Authors (Akinnubi and Adeniyi, 2017; Varanasi and Tripathi, 2016; Hernandez and Madrigal, 2014; Panofsky and Brier, 1960). It is a powerful technique in decomposing the whole time series into a set of components each with a variance smaller than that of the original records. Hence, each component may account for a certain percentage of the total variance. The number of components is chosen based on the percentage of total variance explained. In practice, although 90% explanation is adopted as acceptable for varying irregular records such as wind speed, it may be taken as 80% which is adopted herein.

Let a sequence $X_1, X_2, X_3,$ …………………and X_n be the wind speed measurement sequence available at a site over a given time period, T. Then, the harmonic analysis method determines the amplitude (A) and phase angle (∅) of a periodicity such that data comprise only perfect sine curves of known periods T and submultiples of the case of a given time series X_t ; and taking t=0 as origin, X_t can be decomposed into sine signal as follows:

$$X_t = \bar{X} + A_1 \sin\left(\frac{2\pi}{T}t + \emptyset_1\right) + A_1 \sin\left(\frac{4\pi}{T}t + \emptyset_2\right) + \dots\dots\dots A_n \sin\left(\frac{2n\pi}{T}t + \emptyset_n\right) \qquad 1$$

In which $\bar{X}$ is the arithmetic average of the original data series, and the other terms on the right-hand side represent the first, second, third……..and nth harmonics over duration T

Furthermore, the wind speed time series can be decomposed into sine and cosine components as

$$X_t = \bar{X} + \sum_{i=1}^{n} \left[\left[a_1 \cos\frac{2\pi}{T}lt + b_1 \sin\frac{2\pi}{T}lt\right]\right] \qquad 2$$

Where a_1 and b_1 are the components of the concerned harmonic i.e ith harmonic. If there are n terms such as $X_1, X_2 \dots\dots.. and\ X_n$ multiplied in term by $\cos 0.\cos\frac{2}{T}\dots\dots\dots$.e.t.c, and the n products are summed, It becomes clear that the majority of the predictions cancel each other out, and the remaining terms $\frac{1}{2}na$.

The total variance is equal to the variance of the observer.

$$a_1 = \frac{2}{n}\sum_{l=0}^{n-1} X_l cos\left(\frac{2\pi}{12}lt\right) \qquad 3$$

$$b_1 = \frac{2}{n}\sum_{l=0}^{n-1} X_l sin\left(\frac{2\pi}{12}lt\right) \qquad 4$$

The amplitude of a given harmonic is

$$A_i = \sqrt{{a_l}^2 + {b_l}^2} \qquad 5$$

Furthermore, the phase of the ith harmonic can be

$$\emptyset_l = arc\tan\left[\frac{b_l}{a_l}\right] \qquad 6$$

Finally, the variance of a given harmonic can be calculated as

$$V_l = \frac{{A_l}^2}{2} \qquad 7$$

2.2.2 Gregory Sinusodal Model (GSM): Gregory (1989) modeled the cyclic behavior of the wind speed U_n during the day as follows

$$U_n = U + (U_{max} - U) \cos\left[2\pi\left(\frac{t - t_{max}}{24}\right)\right] \quad 8$$

Where *t* is the time of the day and t_{max} is the time when the maximum wind speeds.

The model was modified and written as

$$U_m = U + (U_{max} - U) sin\left[2\pi\left(\frac{t - t_{max}}{24}\right)\right] exp\left[\frac{t}{t_{max}}\right] \quad 9$$

2.3.1 Ephrath Sinusodal Model (ESM): Saito *et al*. (2006) and Ephrath *et al*. (1996) proposed a sinusoidal model for modelling the diurnal wind speed (u) curve which is based on its behaviour during stable and unstable conditions. The diurnal wind speed curves appeared to be characterized using the following time constants; T_1 is the time in which the wind speed increases from the minimum value (after sunrise); T_2 is the time of maximum wind speed (after solar noon) and T_3 is the time it decreases back to a minimum (after sunset).

$$u = u_{\min} + u_{\max} \sin\left[2\pi \frac{(t - t_{w1,2})}{SF_{1,2}}\right] \quad 10$$

Where $t_{w1,2}$ and $SF_{1,2}$ are time interval factors that depend on the time duration in which wind speed increases or decreases, respectively. It should be noticed that $t_{w1,2}$ and $SF_{1,2}$ are not independent of each other. Their values are related to the time constant as follows (Eq. 10)

$$\left.\begin{aligned} t_{w1} &= T_1 \\ t_{w2} &= 2(T_2 - T_3) \\ SF_1 &= 4(T_2 - T_1) \\ SF_2 &= 2(T_3 - T_2) \end{aligned}\right\} \quad 11$$

The required inputs are maximum and minimum wind speed values, these values can be expressed (Saito *et al*., 2006) as

$$U_{max} = \frac{2u_r}{1 + u_r} u \quad 12$$

$$U_{min} = \frac{2}{1 + u_r} u \quad 13$$

Where u_r is the ratio of maximum to minimum wind speed and the value will be calculated using measured data. As stated in Table 1, the required inputs for the two experimental locations have been calculated.

Table 1: Data used for the calculation of diurnal pattern of wind speed.

Location(S)	DOY	Time Constant(s)			u_{max}	u_{min}	u_r
		T_1 Hours after Sunrise	T_2 Hours after Noon	T_3 Hours after Sunset			
ILE-IFE SITE	55	1	6	6	2.90	0.11	26.36
	56	2	5	3	2.80	0.12	23.33
	57	1	8	2	2.13	0.16	25.81
	60	2	7	4	3.04	0.33	29.21
	61	2	6	4	2.03	0.21	19.19
IBADAN SITE	56	2	6	7	3.19	0.14	22.78
	57	2	8	4	3.21	0.23	23.95
	61	1	9	3	2.67	0.33	21.34
	80	3	8	4	2.72	0.27	10.07
	81	2	7	6	2.33	0.02	23.84

2.3 Data Analysis

To evaluate the efficiency of the models, their results are compared to the measured dataset considering statistical means. The MBE (average deviation between parameterized and measured data; and the RMSE (average positive distance between parameterized and measured data). The MBE and RMSE were calculated

$$MBE = \sum \frac{(u(Observed) - u(predicted)}{n} \qquad 14$$

$$RMSE = \sqrt{\sum \frac{(u(Observed) - u(predicted)^2}{n}} \qquad 15$$

where n is the number of observation (Evans et al. 1993; de Miguel et al. 2001).

3.0 Results and Discussion

3.1: Mean Diurnal Wind Speed for the two sites

Figures 3–4 show the results of an hourly analysis of the calculated and observed mean wind speed (u) for the Ile-Ife and Ibadan locations. The mean diurnal wind speed range at the Ile-Ife location for the period under consideration was 2.89 ms^{-1} for wet days and 2.26 ms^{-1} for dry days throughout the study period. The mean diurnal wind speed value was 2.67 ms^{-1} for the whole period. The mean diurnal u range for the Ibadan site was 2.79 ms^{-1} for wet days and 2.38 ms^{-1} for dry days, respectively, whereas the overall mean diurnal (u) was 2.66 ms^{-1} for both wet days and dry days. The diurnal fluctuation in wind speed was significantly more prominent on wet days than on dry days, indicating that the wind was more variable over the wet days. This occurs as a result of the faster-moving air at higher altitudes colliding with the air near the surface (Gregory et al., 1994).

Although the predicted wind speed using the ESM model fluctuates smoothly and approximates the measured wind speed, the detailed fluctuations could not be correctly represented. For daylight scenarios, the ESM model approximates the overall trend of the measured value, however, the model was significantly underestimated for night-time situations. It was also shown by the graphs that the two sine curves could be used to illustrate the rise and decrease in wind speed throughout the daylight hours (Figures.3- 4). According to the physical qualities of the place and the distance from the oceans, the lowest wind speed values may differ from one location to another,

The GSM model was able to predict wind speed variations that are progressively changing because of the use of a trigonometric function, even though the calculated wind speeds were significantly underestimated and could not be appropriately reproduced. The HAT model proved average performance in both dry and wet situations by creating a sinusoidal curve that statistically described the fluctuation of wind speed, although the model was significantly underestimated on both wet and dry days. A further significant advantage of the HAT model was that it was capable of replicating variations that were not feasible to produce using the GSM model. It was revealed that the second harmonics dominate the variance in hourly wind speed at the two research sites, resulting in two cycles of change across 24 hours between the two study sites. Overall, both the HAT and GSM models perform well in terms of forecasting the overall pattern of wind speed throughout the days given the average daily value, although they were strongly underestimated.

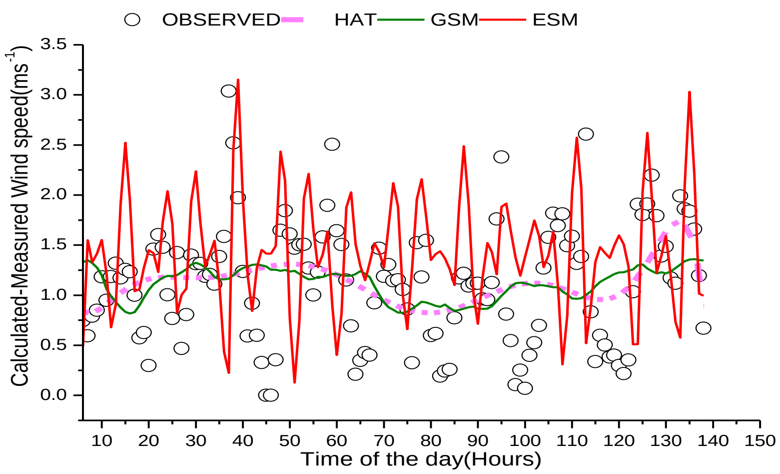

Figure 3: Hourly comparison of measured and modeled hourly wind speed for DOY 55 -61, Ibadan study site, 2007.

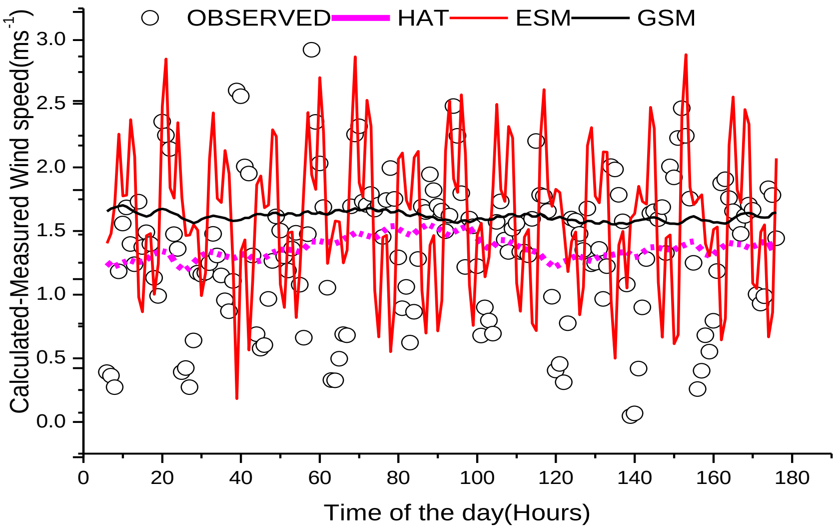

Figure 4: Hourly comparison of observed and calculated wind speed of three models at Ile-Ife site for DOYs 55-70, 2004.

To illustrate the degree of agreement between observed and modeled wind speeds, Table 2 shows their correlation coefficients (r^2, MBE, and RMSE). The lowest values of MBE and RMSE found for wet days using the ESM model for the Ibadan site are -0.10 ms^{-1} and 0.55 ms^{-1}, respectively, whereas the lowest values obtained for the Ile-Ife site are -0.20 ms^{-1} and 0.74 ms^{-1}, respectively. On dry days, the MBE and RMSE values for the Ibadan site are -0.16 ms^{-1} and 0.64 ms^{-1}, respectively, while the values for the Ile-Ife site are -0.06 and 0.76, respectively. The significance of these findings was that the ESM demonstrated superior performance when compared to other models that were evaluated at two locations. The findings also demonstrated that the performance of ESM at the Ibadan location was better on rainy days (RMSE = 0.55 ms^{-1}) than it was on dry days (RMSE = 0.64 ms^{-1}). When the two locations were compared, the Ibadan site performed much better in terms of ESM performance than the Ife site. While GSM performance was quite average at both locations (r^2 = 0.50 for the Ife-Ile site on wet days and r^2 = 0.58 for the Ibadan site on wet days), HAT performance was poor at both locations on wet and dry days (MBE = 3.02 ms^{-1} – 4.05 ms^{-1}), even though both sites had quite average GSM performance.

Table 2: Summary of the RMSE/MBE errors and linear regression parameters

Model(s)		PERIODS	MBE(ms^{-1})	RMSE(ms^{-1})	r^2	a(Intercept)	b(Slope)
HAT	Ibadan site	WET	4.02	7.48	0.46[b]	2.65	3.33
		DRY	5.02	9.48	0.45[b]	4.56	2.78
	Ile-Ife site	WET	3.56	6.05	0.44[b]	3.95	3.73
		DRY	3.02	6.00	0.42[b]	4.08	2.78
GSM	Ibadan site	WET	0.80	2.82	0.50[a]	0.70	0.45
		DRY	0.90	2.89	0.51[a]	1.70	1.98
	Ile-Ife site	WET	1.83	2.88	0.58[a]	2.70	3.45
		DRY	1.96	2.90	0.56[a]	1.75	2.98
ESM	Ibadan site	WET	-0.10	0.55	0.82[a]	0.89	0.87
		DRY	-0.16	0.64	0.70[a]	-1.56	0.85
	Ile-Ife site	WET	-0.20	0.74	0.69[a]	-0.75	1.39
		DRY	-0.06	0.76	0.65[a]	-0.19	1.63

a- significant correlation at 5% level of significance; b- not significant correlation at 5% level of significance

Due to the similar climatic conditions at the two locations and the findings from the study, the data from the Ibadan site will be utilized to explore the influence of atmospheric pressure on wind speed during the transitional period under review. Figure 5 and Figure 6 represent the composite diurnal effects of atmospheric pressure on wind speed in wet and dry days for the Ibadan site. The average atmospheric pressures recorded for wet and dry days were 985 mmHg and 982 mmHg, respectively. This implies that the atmospheric pressure for wet days was higher than that for dry days. This might be attributed to atmospheric stability during the transition phase from a wet to a dry environment, and it could result in a decrease in the density of our atmosphere, which would result in an increase in temperature extremes between the hours of day and night. (Foken, 2003).

In Figure 5, the wind speed seemed to be at its maximum around midday, when the associated atmospheric pressure was rather high (936.6 mmHg). Additionally, the graph indicates that during the early hours of the morning, a low wind speed range between 0.167 ms^{-1} and 0.607 ms^{-1} was seen, together with a correspondingly high atmospheric pressure. In the early hours of the morning, the value of atmospheric pressure was almost steady (984mmHg). Additionally, during rainy days, high atmospheric pressure resulted in relatively modest wind speeds throughout the mid-day (1100 LST hrs -1200 LST hrs). Between 1800 LST hrs and 2000 LST hrs, the atmosphere suffered from severe turbulence. The wind speed was almost minimal in the early morning hours.

As seen in Figure 6, the abrupt decrease in air pressure during the late morning hours (600–1200 LST hrs) decreased the wind speed to 0 m/s Wind speeds ranged from a maximum of 3 ms^{-1} when the corresponding air pressure was 988.3 mmHg to 1.6 ms^{-1} in the middle of the day when the air pressure was 988.3 mmHg. Wind speeds fluctuated between 2.24 ms^{-1} and 2.80 ms^{-1} during the early hours of the night, while air pressure varied between 934 mmHg and 984 mmHg. The air pressure was 985 mmHg in the late hours of the night, with wind speeds ranging from 1.83 ms^{-1} to 1.13 ms^{-1}. This implies that when the atmospheric pressure is high, the wind speed is low, and vice versa.

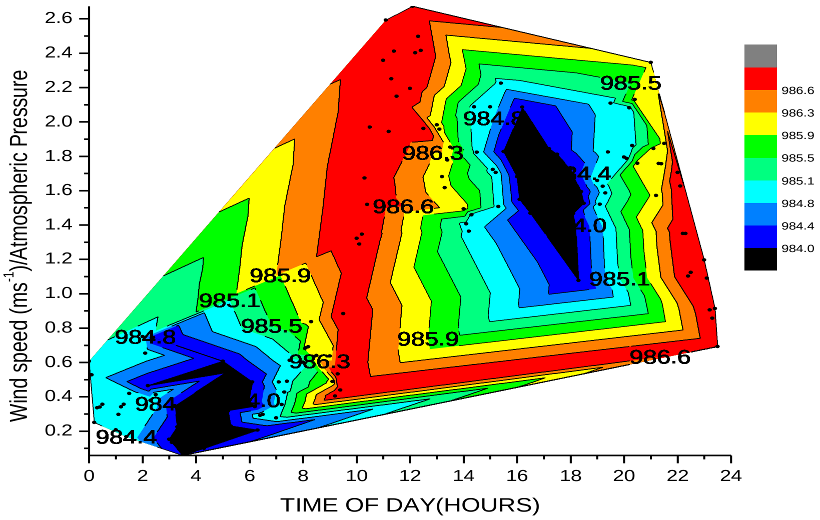

Figure 5: Composite Diurnal Effect of Atmospheric Pressure on Wind Speed in wet day (Ibadan Site).

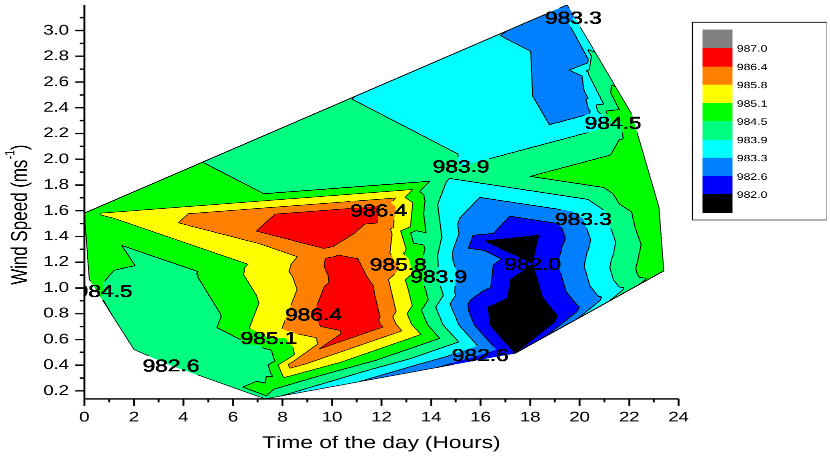

Figure 6: Composite Diurnal Effect of Atmospheric Pressure on Wind Speed in Dry days (Ibadan Site)

CONCLUSION

When placed in this humid climate, the three diurnal wind speed models evaluated throughout the transition period for the two sites under consideration each reflects a distinct feature of the tropical environment. The Ephrath Sinusoidal Model outperformed the other models in terms of accuracy and efficiency, according to the analysis of the results. Although several factors may aid its performance, real-time observations demonstrated that the model's temporal constants and needed inputs were inferred from field data. This appears to improve its performance in this area. When compared to observed readings, the Ephrath Sinusoidal Model revealed that wind speed variability features are often similar. Even though the Gregory Sinusoidal Model's modeled wind speed for this location was substantially underestimated, a moderate wind speed trend was observed. To parametrize the diurnal wind speed pattern in this humid environment, the Harmonic Analysis Technique must be significantly improved. The Ephrath Sinusoidal Model establishes that it has a sound methodology and that it may be applied anywhere where local atmospheric variables influence wind speed based on the results. Finally, the model generated predicted results that apply to the region, however other climate zones may require minor revisions.

5.0. Acknowledgement

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REFERENCES

Akinnubi, R. T. and Adeniyi, M. O.(2019). The Improvement Of Turbulent Heat flux Parameterization For Use In the Tropical Regions Using Low Wind speed Excess Resistance Parameter. *Journal of Advances in Modeling Earth Systems*, 4, 11-18, https://doi.org/10.1029/2018MS001466

Akinnubi, R.T and Adeniyi, M.O. (2017). Modeling of diurnal pattern of air temperature in a tropical environment: Ile-Ife and Ibadan, Nigeria. Modeling Earth Systems and Environment, 3, 1421-1439.

Beyer, H. G., Nottebaum, K., (1995). Synthesis of long-term hourly wind speed time series on the basis of the european wind atlas data. Solar Energy 54 (5), 351–355.

Bianco, L., Djalalova, I. V., Wilczak, J. M., Cline, J and Calvert, S.(2016). A wind energy ramp tool and metric for measuring the skill of numerical weather prediction models. Weather

Billington, R., Chen, H., Ghajar, R., (1996). A sequential simulation technique for adequacy evaluation of generating systems including wind energy. IEEE Transactions on Energy Conversion 11 (4), 728–734. Box, G. E. P., Jenkins, G. M., 1976. Time Series Analysis: Forecasting and Control. Holden-Day.

Bowman, K.-P.; Collier, J.-C.; North, G.-R.; Wu, Q.; Ha, E.; Hardin, J (**2005**). Diurnal cycle of tropical precipitation in Tropical Rainfall Measuring Mission (TRMM) satellite and ocean buoy rain gauge data. J. Geophys.

Res., 110, 1–14. [Google Scholar] [CrossRef]
Castellanos, F., Ramesar, V. I. (2006). Characterization and estimation of wind energy resources using autoregressive modelling and probability density functions. Wind Engineering 30 (1), 1–14.
Castro Sayas, F., Allan, R. N. (1996). Generation availability assessment of wind farms. IEEE Proceedings - Generation, Transmission and Distribution 143 (5), 507–518.
de Miguel A, Bilbao J, Aguiar R, Kambezidis H, Negro E (2001) Diffuse solar irradiation model evaluation in the north Mediterranean belt area. Sol Energy 70:143–153
Elmore, A. C., Gallagher, R., (2009). Using regional climate center data to predict small wind turbine performance. Practice Periodical of Hazardous, Toxic, and Radioactive Waste management (January), 14–19.
Ephrath, J.E., Goudriaan, J., Marani, A. (1996). Modelling diurnal patterns of air temperature, radiation, wind speed and relative humidity by equations from daily characteristics. Agricultural Systems 51 (4), 377–393.
Essenwanger O M (2001) Classification of climates, world survey of climatology 1C, general climatology. Elsevier, Amsterdam, 102 pp, 10: 0444882782
Evans M, Hastings N, Peacock B (1993) Statistical distributions. Wiley, New York, pp 56–67
Foken T (2003) Angewande meteorologie. Mikrometeorologische methoden. Springer, Heidelberg, p 289
Frank, C., Pospichal, B., Wahl, S., Keller, J. D., and Hense, A. (2020). The added value of high resolution regional reanalyses for wind power applications. *Renew. Energy* **148**, 1094–1109. doi:https://doi.org/10.1016/j.renene.2019.09.138 [Crossref], [Web of Science ®], [Google Scholar]
Gregory, J.M. (1989). Wind data generation for Great Plains locations. American Society of Agricultural Engineers, New Orleans, LA. Forecast. 31, 1137–1156. doi:https://doi.org/10.1175/WAF-D-15-0144.1 [Crossref], [Web of Science ®], [Google Scholar]
Gregory, J.M., G.R. Wilson, and R.C. Vining. (1996). Modeling hourly and daily wind and relative humidity. International Conference on Air Pollution from Agricultural Operations. Midwest Plan Service, Ames, IA, p 183-190.
Gregory, J.M., R.E. Peterson, J.A. Lee, and G.R. Wilson. (1994). Modeling wind and relative humidity effects on air quality. International Specialty Conference on Aerosols and Atmospheric Optics: Radiative Balance and Visual Air Quality. Sponsored by Air and Waste Management Association and American Geophysical Union, Snowbird, Utah p 183-190.
Hagninou E. V. Donnou, A B. Akpo, Clément A. Kouchadé, Basile B. Kounouhewa, Guy H. Hounguè, Gbènoukpo F. Nonfodji, Julien D,(2019) "Vertical Profile of Wind Diurnal Cycle in the Surface Boundary Layer over the Coast of Cotonou, Benin, under a Convective Atmosphere", Advances in Meteorology, vol. 2019, Article ID 7530828, 18 pages, 2019. https://doi.org/10.1155/2019/7530828
He Y, Monahan A H and McFarlane NA. (2013). Diurnal variations of land surface wind speed probability distributions under clear-sky and low-cloud conditions. Geophysical

Research Letters 40(12):1–7, DOI: 10.1002/grl.50575.
Hernandez E and Madrigal M.(2014) A step forward in the modelling of the doubly fed induction machine for harmonic analysis. IEEE Transaction Energy Conversion. 2014;29(3):149-157
Jegede O O, Okogbue EC and Balogun E E (2004) Proceedings of the workshop and the Nigeria Micro-meteorological experiment (NIMEX – 115 July 2004,), Ile-Ife, Nigeria.
Kennedy, S., R. P (2003). A probabilistic model for simulating long-term wind-power output. Wind Engineering 27 (3), 167–181.
Kunal D, John C, Michael K, Gilles Be, Rajnish S (2020). Evaluation of the WRF model for simulating surface winds and the diurnal cycle of wind speed for the small island state of Fiji. Journal of Physics: Conference Series, IOP Publishing,, 1618, pp.062025. 10.1088/1742-6596/1618/6/062025
Otunla FA And Oladiran OA (2013) Evaluation Of Soil Thermal Diffusivity Algorithms At Two Equatorial Sites In West Africa Annals Of Geophysics, 56, 1, 2013, R0101; Doi:10.4401/Ag-617.
Panofsky, HA and Brier, GW. (1960) Some Applications of Statistics to Meteorology. The Pennsylvania State University Mauder M.,Jegede OO, Okogbue EC, Winmer.F and Foken T (2006) Surface Energy balance measurement at a tropical site in West Africa during the transition from dry to wet season.Theor.Appl Climatol.88. 171-183.
Saito, H., Šimu˚ nek, J., Mohanty, B.P. (2006). Numerical analysis of coupled water, vapor, and heat transport in the vadose zone. Vadose Zone Journal 5, 784–800.
Sebastian B, Jan D. K and Sabrina W (2021) Evaluation of wind speed estimates in reanalyses for wind energy applicationsAdv. Sci. Res., 18, 115–126, https://doi.org/10.5194/asr-18-115-2021
Shamshad, A., Bawadi, M. A., Wan Hussin, W. M. A., Majid, T. A., Sanusi, S. A. M., (2005). First and second order markov chain models for synthetic generation of wind speed time serie. Energy 30, 693–708.
Varanasi J and Tripathi MM (2016) A comparative study of wind power forecasting techniques — A review article. In: 3rd International Conference on Computing for Sustainable Global Development (INDIACom). New Delhi; . pp. 3649-3655
Vining, R.C. and M. Allen (1993). Consideration of the air resource through total resource management. IN Integrated Resource Management and Landscape Modification for Environmental Protection. Proceedings of the International Symposium, Chicago, IL. American Society of Agricultural Engineers, St. Joseph, MI, p 20-28.
Yang, G.-Y.; Slingo, J.(2001): The diurnal cycle in the tropics. Mon. Weather Rev., 129, 784–801. [Google Scholar] [CrossRef]
Zuidema, P.(2003) Convective clouds over the Bay of Bengal. Mon. Weather Rev., 131, 780–798. [Google Scholar] [CrossRef].