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TIME SERIES ANALYSIS OF WIND SPEED VARIABILITY OVER PARTS OF THE UNITED KINGDOM FROM SATELLITE ALTIMETRY AND IMPLICATIONS FOR ENGINEERING INFRASTRUCTURE

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Abstract

Wind speed is a potential source of wind energy of immense socio-economic benefits on one hand, and on the other hand, one of the climate change variables that has the capacity of causing disasters in open regions of the world, when not well understood, classified and mitigated. This study aims at the time series analysis of wind speed modulus (WSM) over selected cities in the United Kingdom and implications for engineering infrastructure. The ten (10) randomly selected locations include, London, Manchester, Nottingham, Glasgow, Bristol, Cardiff, Norwich, Canterbury, Newcastle Upon Tyne and Edinburgh. The global merged near real time satellite altimetry datasets of year 2013-2019 over the United Kingdom were used to examine the variability of the wind speed, and determine if its values are at the scale of storm or hurricane, or if poses critical risk and threat to specific engineering infrastructure in the selected locations across the UK. The months of April-June (parts of spring and summer seasons) showed a period of minimum WSM, while late November-February (winter season) showed a period of maximum wind speed values in the study area. The estimated minimum, average and maximum wind speed values for each location ranged between light breeze (scale 1) and fresh gale wind (scale 8) (i.e., between 0.5m/s and 20m/s). The average wind speed ranged from 6.93-7.8m/s; hence classified as moderate breeze (i.e., between 5.5 and 8 m/s). On the other hand, the maximum wind speed ranged from 16.9m/s -18.9m/s; hence classified as fresh gale wind, which can make walking against the wind direction very difficult during the wind event. The study revealed that, the WSM values were not at the scale of storm and hurricane (i.e., WSM of 28m/s – over 32m/s); hence considered not of critical risk and threat to average high-rise engineering buildings and infrastructure in the study area. The highest range of the dynamic force of wind load was about 2149N (2.15kN) recorded in Edinburgh, while the minimum force was about 6.13N (0.006kN) recorded in Canterbury. The computed dynamic force of wind load on hypothetical surface area of features and space in the selected locations is a relevant advisory information for resilience infrastructure designs, and in particular for wind farm feasibility planning and development in the study area. The linear regressions of the WSM in London against those of Edinburgh and Manchester showed excellent spatial correlations with R^2 values of 92.14 % and 97.69% respectively, but with a better fit between London and Manchester than London and Edinburgh due to spatial contiguity. The study recommends the inclusion of analysed WSM metrics in the design, construction and management of critical engineering infrastructure in order to mitigate climate change-induced failures and enhanced life-span and safety of the infrastructure. The inherent potential of wind energy from wind speed should be exploited for sustainable renewable energy ecosystem in the UK.

Keywords: Time Series Analysis, Climate Change, Wind Speed, Satellite Altimetry, Engineering Infrastructure

1.0 INTRODUCTION

Achieving sustainable quality, reliable and resilient infrastructure in modern days of adverse climate change phenomena requires multi-mission and multi-thematic geospatial datasets in order to effectively design, build, monitor and manage location suitability, stability and safety of the infrastructures (*transport and roads, bridge, buildings, dam structure, utilities, industrial and manufacturing, power, science/technology and communication, support service, landscape and environment, socio-economic, etc.,).* Wind speed phenomena is one of the climate change variables that has the capacity of causing disasters in open regions, when not well understood, classified and mitigated. On the other hand, it is a massive source of wind energy, which is considered as one of the most promising and economical renewable energy [12].

The wind speed is the satellite altimetry derived surface wind speed modulus over ocean and land. They are however more accurate over the ocean than the land surface due to deterioration of satellite radar altimetry echoes over land area. The availability of multi mission satellite observations, retrievals and assimilation of atmospheric variables present unique opportunity for atmospheric science and climate change researches across the globe [14]. Using radar technology and vector retrieval method, the wind speed distribution, wind direction and air density etc., can be accurately measured [10; 7]. The limitation of current satellite altimetry techniques of wind speed observation is its inability to accurately capture or measure wind speeds beyond 20-25m/s, but when integrated with other wind speed devices, greater results are feasible. However, the advantage of its synoptic coverage of large area and rapidity and repeatability of observations, satellite altimetry still suffice for investigating WSM in volatile inaccessible climatic regions for disaster early warning and mitigation.

The radar technology used in wind speed measurements in complex terrain is in-depth studied, the results show that under the moderately complex terrain condition, the radar measurement error is 3-4%, and in complex terrain condition, the radar measurement error up to 10% [3]. The emerging energy crisis in Europe, partly due to the raging Russia-Ukraine war is a clarion call for alternative means of renewable energy such as wind. Excess wind speed has the capacity of causing disaster to engineering infrastructure, but also have the benefits of been converted and used as wind farm for power turbines. Wind speed forecasting is critical for wind energy conversion systems since it greatly influences the issues such as the scheduling of a power system, and the dynamic control of the wind turbine [11].

Natural Wind Spectrum

The natural wind speed can be represented by equation (1.1) [7]

$$\begin{cases} U = \bar{U}(z) + u(y,z,t) \\ v = v(y,z,t) \\ w = w(y,z,t) \end{cases} \tag{1.1}$$

Where $\bar{U}$ is the longitudinal average wind speed of a point in the flow field, u is the longitudinal fluctuating wind speed, v is the lateral fluctuating wind speed; w is the vertical fluctuating wind speed.

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Under the condition of neutral atmosphere, without considering the Coriolis effect, the longitudinal average wind speed $\bar{U}(z)$ can be obtained by equation (1.2).

$$\bar{U}(z) = \frac{u_0}{k}\ln(z/z_0) \qquad (1.2)$$

Where u_o is the friction velocity, k is the von Karman constant, z_o is the surface roughness. Under the condition of neutral atmosphere, the value of k is 0.4.

As a result of the fluctuating property of wind velocity, the natural wind have random characteristics, hence the changes of the three fluctuating wind speeds are independent of each other, which can be described by wind speed spectrum [7]. The slope of the Kaimal spectrum changes greatly in the low-frequency part, thus the Kaimal spectrum can more accurately describe the turbulence characteristics of wind. [7] used the Kaimal spectrum to describe the fluctuating wind speed, and represented the spectrum of the three fluctuating wind speed by equations (1.3), (1.4) and (1.5) respectively.

$$S_u(f) = u_0^2 \frac{52.5(z/\bar{U}(z))}{(1+33(z/\bar{U}(z))f)^{5/3}} \qquad (1.3)$$

$$S_v(f) = u_0^2 \frac{8.5(z/\bar{U}(z))}{(1+9.5(z/\bar{U}(z))f)^{5/3}} \qquad (1.4)$$

$$S_v(f) = u_0^2 \frac{1.05(z/\bar{U}(z))}{(1+5.3(z/\bar{U}(z))f)^{5/3}} \qquad (1.5)$$

The satellite altimetry measures the wind speed by using the frequency and wave length of the radar (wind speed = fλ). The speed is determined in the three (*u*, *v* and *w*) dimensions, but the x-axis velocity distribution of the longitudinal fluctuating wind speed is readily most available and used for climate change studies. In ocean wave speed, because of relevance of depth in the circulation, the u and v velocity components are equally measured. In this application, interest is on the horizontal (x-axis) velocity distribution of the longitudinal fluctuating wind speed such as shown by figure 1.0.

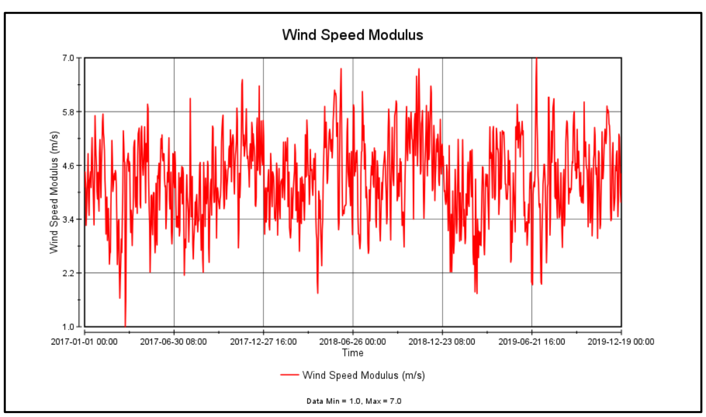

Figure 1.0: A Typical Fluctuating Wind Speed Modulus at a selected location (*lat. 4S/long. 4E*) in *Nigerian Territorial Waters, Gulf of Guinea* (2017-2019)

The Sentinel-3 mission is able to monitor wind speed from 0.5m/s to 20 m/s (about 1 to 46 mph) and very significant in coastal engineering, for improving safety in outdoor locations to assessing potential sites for wind power projects, meteorology, climatology and oceanography, etc. Table 1 presents the Beaufort Wind Scale required for the classification and description of the specific wind speed.

Table 1: Beaufort Wind Scale [Source: 9]

Scale/Class	Wind speed	Descriptions/Effects
0 -- Calm	less than 1 mph (0 m/s)	Smoke rises vertically
1 – Light Air	1 - 3 mph (0.5-1.5 m/s)	Smoke drifts with air, weather vanes inactive
2 – Light breeze	4 - 7 mph (2-3 m/s)	Weather vanes active, wind felt on face, leaves rustle
3 – Gentle breeze	8 - 12 mph (3.5-5 m/s)	Leaves & small twigs move, light flags extend
4 -- Moderate breeze	13 - 18 mph (5.5-8 m/s)	mall branches sway, dust & loose paper blows about
5-- Fresh breeze	19 - 24 mph (8.5-10.5 m/s)	Small trees sway, waves break on inland waters
6 – Strong breeze	25 - 31 mph (11-13.5 m/s)	Large branches sway, umbrellas difficult to use
7 --- Moderate gale	32 - 38 mph (14-16.5 m/s)	Whole trees sway, difficult to walk against wind
8 --- Fresh gale	39 - 46 mph (17-20 m/s)	Twigs broken off trees, walking against wind very difficult
9 --- Strong gale	47 - 54 mph (20.5-23.5 m/s)	Slight damage to buildings, shingles blown off roof
10 -- Whole gale	55 - 63 mph (24-27.5 m/s)	Trees uprooted, considerable damage to buildings
11 -- Storm	64 - 73 mph (28-31.5 m/s)	Widespread damage, very rare occurrence
12 -- Hurricane	over 73 mph (over 32 m/s)	Violent destruction

Surface wind and wind-wave data are very important information for a wide range of planning and design of coastal and marine activities and engineering infrastructure. Therefore, sustainable operational and monitoring activities in coastal cities and regions require nowcast or forecast wind information. The sources of wind and wave data can be divided into three main categories: in-situ measurements, remote sensing observations and numerical model estimates [1; 2]. Since the 1990s, satellite remote sensing techniques have advanced tremendously with the introduction of satellite missions or multi-mission and constellations. The collection, integration and use of highly temporal and synoptic satellite altimetry data of earth and sea surface targets, with limitless access and high accuracy and reliability are of great interest to the management of the geophysical parameters around earth features [13; 15; 16]. Instruments like Radar Altimeter (RA), Synthetic Aperture Radar (SAR) and Scatterometer (SCAT) with excellent global coverages and relative reliability are used to measure surface winds and ocean waves [17; 1; 2]. The wave speed parameters are obtained by analysing the shape and intensity of the altimeter radar beam reflected from the earth and sea surface (radar echo).

Objectives of the Study

The objectives of the investigation are to:

i. evaluate the spatial and temporal variability of wind speed modulus (WSM) from satellite altimetry over selected cities in the United Kingdom;
ii. determine if the prevailing WSM poses critical risk and threat to specific engineering infrastructure in the selected locations across the UK;

iii. compute the dynamic force of wind load on surface areas of features and space in the study area;
iv. recommends strategies for integrating WSM metrics in sustainable infrastructure design and safety

The Study Area

The study area covers ten (10) locations selected randomly across the UK for the exercise. The selected locations include, London, Manchester, Nottingham, Glasgow, Bristol, Cardiff, Norwich, Canterbury, Newcastle Upon Tyne and Edinburgh. Figure 1.0 show the map of the United Kingdom [6], and the spatial geographic coordinates of the selected locations.

S/no	Location	Longitude (λ)	Latitude (ϕ)
1	London	0.13W	51.50N
2	Manchester	2.24W	53.48N
3	Nottingham	1.14W	52.95N
4	New Castle Upon Tyne	1.60W	54.98N
5	Glasgow	4.24W	55.89N
6	Bristol	2.59W	51.45N
7	Cardiff	3.18W	51.48N
8	Norwich	1.29E	52.62N
9	Canterbury	1.08E	51.28N
10	Edinburgh	3.20W	55.95N

Figure 1.0: Map of the United Kingdom [6]

2.0 MATERIALS AND METHODS

Datasets Used and Source

The dataset is archived near real time (NRT) global wind speed modulus (measured in m/s) observed from multi-mission and merged satellite altimetry. The source is the OPeNDAP URL [8], and a part of well determined and reliable aviso altimetry data hub in France. This particular global merged near real time satellite altimetry dataset for the period of 2013-2019. *In this study, the datasets were however not validated by any ground field determinations or traditional terrestrial techniques at the sampled locations, but planned for the future/subsequent phases of the investigations.*

Data Sampling Technique

Ten (10) locations across the UK were randomly selected for the exercise. The selected locations include, London, Manchester, Nottingham, Glasgow, Bristol, Cardiff, Norwich, Canterbury,

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Newcastle Upon Tyne and Edinburgh. They were processed on LAS8./Ferret 7.1 NOAA/PMEL cloud computing device known as live access server (LAS) aviso altimetry. The datasets were further extracted for customized queries and further analysis of each location in other relevant Application Programme Interfaces (APIs) in MS-Excel, Panoply and MatLab. The available data format for the storage and interoperability of WSM datasets include NetCDF, ASCII, CSV and arcGrid.

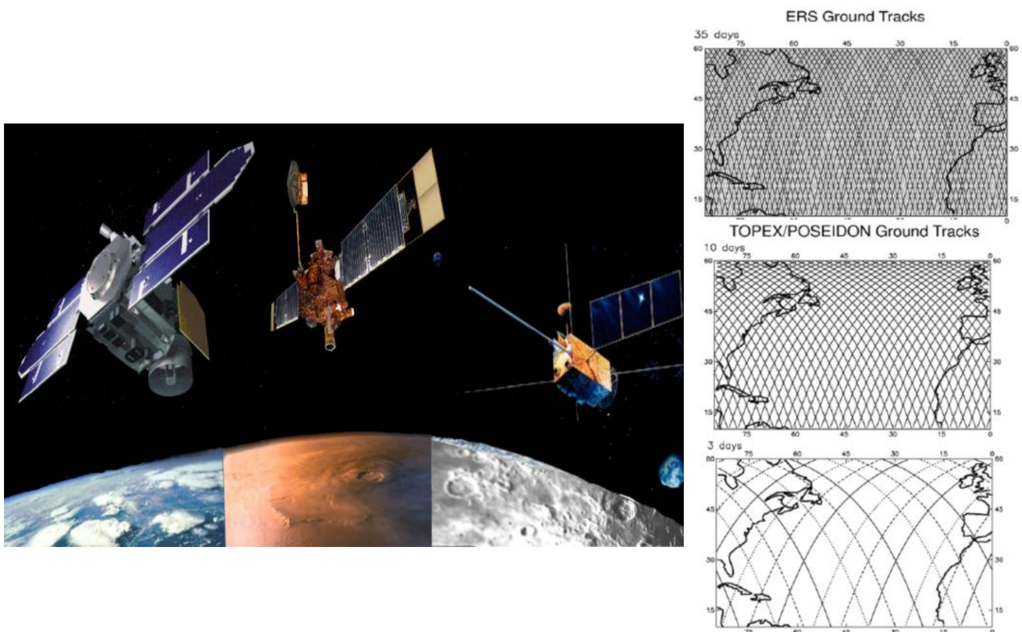

Figure 2.0: Constellation of Multi-mission Satellite Altimetry and Ground Track Data Coverage [4]

Computation of Dynamic Force of Wind Load

Wind act on natural and man-made structures and features on the earth surface. The dynamic force of wind load on surface areas of features and space can therefore be determined, given the air density, and wind velocity. Therefore, given that air density (ρ) is $1.2 kg/m^3$ and values of wind speed (v) and surface area (A) of impact, the dynamic force can be calculated using equation (6) (Note: *1 m/s = 3.6 km/h = 2.237 mph; 1 Pa = 1 N/m*^{2})

$$F_w = \frac{1}{2}(\rho v^2 A) \qquad (2.1)$$

However, in order to calculate the pressure for each wind speed at given point, without considering the loading force on vertical surface area, equation (2.1) can be re-written as equation (2.2).

$$P = (v^2 * \rho)/2 \qquad (2.2)$$

where P is the Pressure from Velocity (pascals), v is the velocity of flow (m/s), and ρ is the density (kg/m^3).

Spatial Correlation Analysis

In order to evaluate the spatial correlation and relationship between the WSM values at the locations, Manchester and Edinburg were randomly selected for regression analysis with the datasets over

London. Therefore, the linear regressions of the WSM at the two locations were independently carried out with the London datasets.

3.0 RESULTS AND DISCUSSIONS

Figures 3a-j show the times series wind speed modulus over ten (10) different selected location across the UK. The results show that, 2019 experienced the least WSM for all the locations, while the highest variable periods were those of 2013 to 2016. However, on the average no station recorded WSM of up to 20m/s (about 46 mph).

Table 2: Selected locations and Computed WSM

S/no	Location	Longitude (λ)	Latitude (ϕ)	Min speed/Date (m/s)	Avg Speed (m/s)	Max speed (m/s)
1	London	0.13W	51.50N	**1.078807** (25/05/17)	6.939620936	**16.94314** (29/11/15)
2	Manchester	2.24W	53.48N	**1.422003** (25/05/15)	7.293685667	**17.37979** (13/02/14)
3	Nottingham	1.14W	52.95N	**1.289207** (25/05/17)	7.272438829	**17.46305** (13/02/14)
4	New Castle Upon Tyne	1.60W	54.98N	**1.301466** (02/06/18)	7.615243722	**18.57737** (13/02/14)
5	Glasgow	4.24W	55.89N	**1.433846** (02/06/18)	7.873696593	**18.84443** (10/01/15)
6	Bristol	2.59W	51.45N	**1.432452** (29/04/14)	7.088808687	**16.61599** (29/11/15)
7	Cardiff	3.18W	51.48N	**1.432452** (29/04/14)	7.088808687	**16.61599** (29/11/15)
8	Norwich	1.29E	52.62N	**1.161384** (25/06/15)	7.2725576	**17.4231** (10/01/15)
9	Canterbury	1.08E	51.28N	**1.010493** (25/05/17)	6.931410107	16.74248 (29/11/15)
10	Edinburgh	3.20W	55.95N	**1.411226** (02/06/18)	7.82687192	**18.92371** (10/01/15)

It is expected that coastal cities and locations experience higher wind speed due to proximity to the ocean circulation effects from the North Sea and Celtic Sea respectively. Table 3 present the description of the wave speed for the study area, based on Beaufort Wind Scale (Table 1).

Table 3: UK wave speed classification based on Beaufort Wind Scale

S/n.	Location Name	Min. speed (m/s)	Avg. Speed (m/s)	Max. speed (m/s)	Description of the prevailing wind speed scale
1	London	1.078807	6.939620936	16.94314	The wind speed ranges between scale 1 **(light breeze (scale 1) and fresh gale wind** (scale 8). [0.5m/s to 20m/s] However, the average wsm for all locations range from 6.93-7.8m/s; hence classified as **Moderate Breeze** (5.5-8 m/s). On the other hand, the values of maximum wind speed at the locations range from 16.9m/s -18.9m/s; hence classified as **Fresh Gale Wind**, which makes walking against the wind very difficult at the period of the occurrence
2	Manchester	1.422003	7.293685667	17.37979	
3	Nottingham	1.289207	7.272438829	17.46305	
4	Newcastle Upon Tyne	1.301466	7.615243722	18.57737	
5	Glasgow	1.433846	7.873696593	18.84443	
6	Bristol	1.432452	7.088808687	16.61599	
7	Cardiff	1.432452	7.088808687	16.61599	
8	Norwich	1.161384	7.2725576	17.4231	
9	Canterbury	1.010493	6.931410107	16.74248	
10	Edinburgh	1.411226	7.82687192	18.92371	

Considering the extreme values of the WSM, Edinburgh recorded the maximum WSM of approximately 18.92m/s, followed by Glasgow and Newcastle Upon Tyne with 18.84m/s and 18.58m/s respectively. These WSM values are however not at the scales of *storm* and *hurricane*, hence considered not of critical risk and threat to average high-rise engineering buildings and other engineering infrastructure in the selected locations across the United Kingdom. Nevertheless, care

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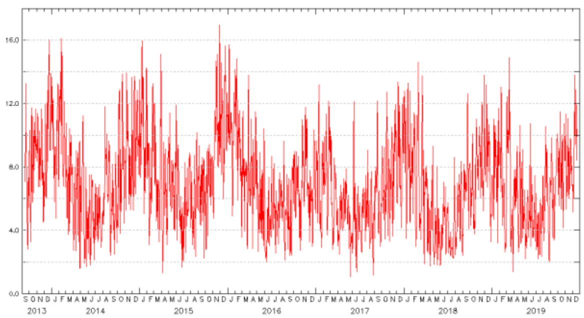
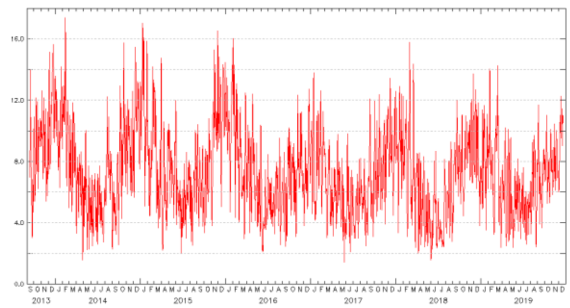
must be taken to adopt appropriate designs and construction of infrastructures that would always withstand any adverse wind event.

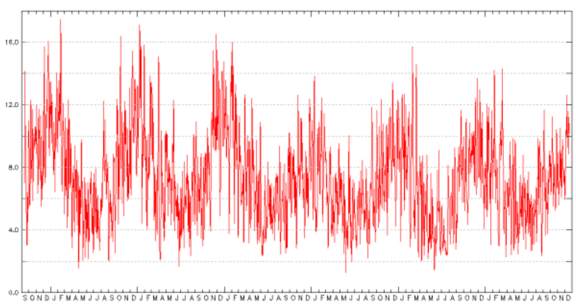
Figures 4a & b are the spatial maps of wind speed modulus merged (m/s) over UK for the start date of data (14-SEP-2013) and end date of the data (19-DEC-2019) respectively. The two figures (a & b) show opposite spatial trend of the WSM phenomena in the *north* and *south* of the UK for *autumn* and *winter* seasons respectively.



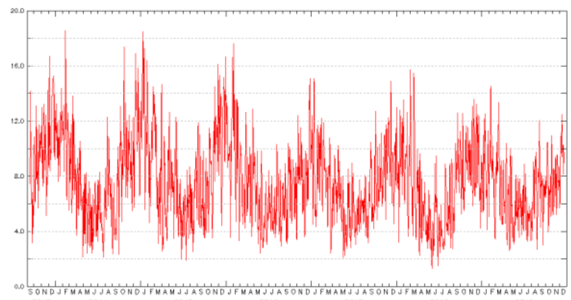
(a): **London**



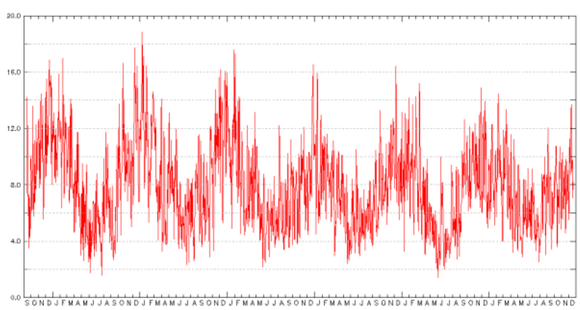
(b): **Manchester**



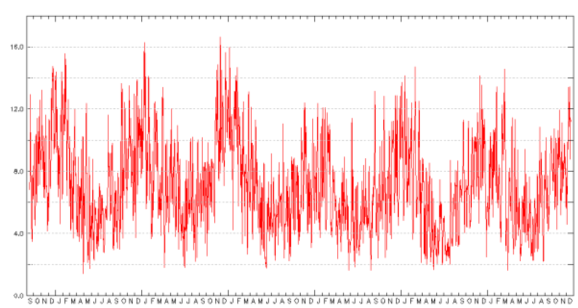
(c): **Nottingham**



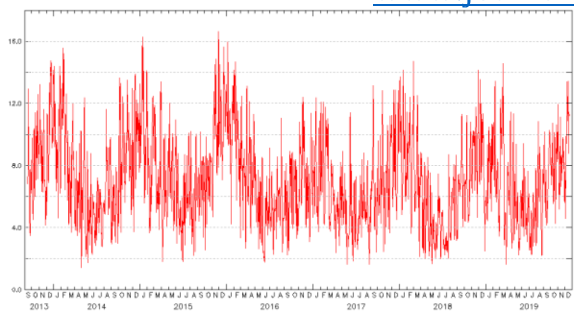
(d): **Newcastle Upon Tyne**



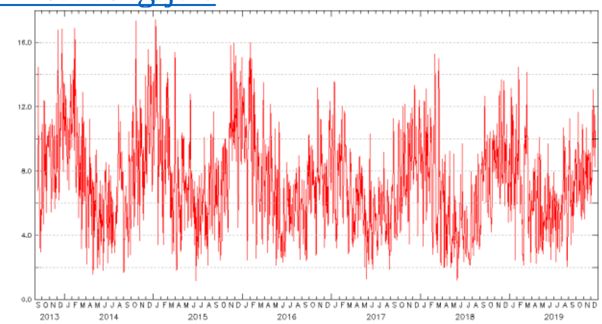
(e): **Glasgow**



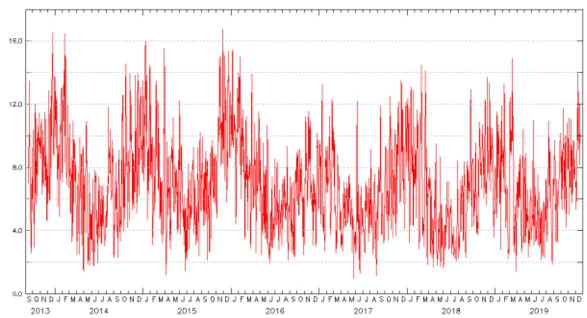
(f) **Bristol**



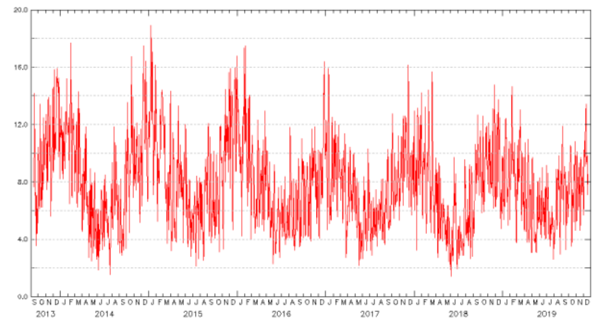
(g) Cardiff



(h) **Norwich**



(i): **Canterbury**



(j) **Edinburgh**

Figure 3 (a-j): Trend of Wind Speed Modulus (m/s) Over Selected Parts of **the United** (2013-2019)

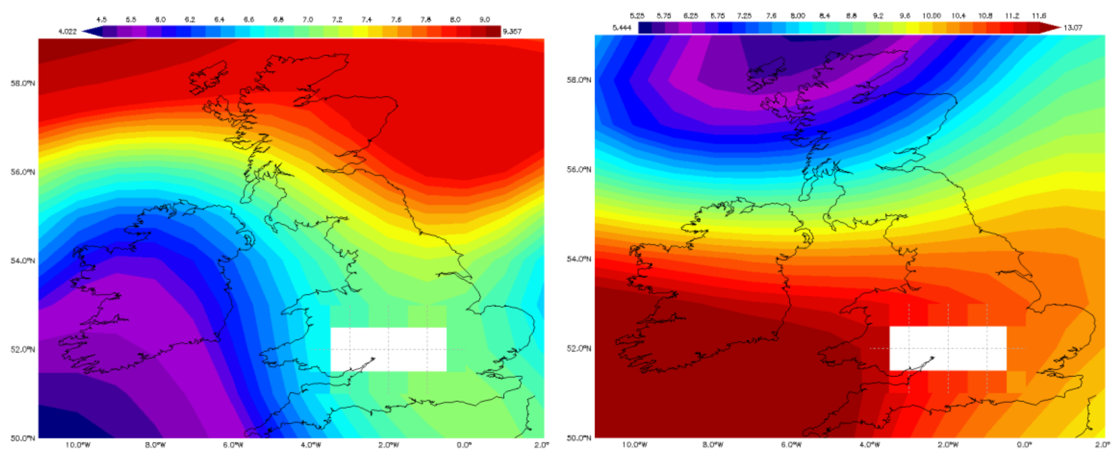


Figure 4: (a) Map of wind speed modulus merged (m/s) over UK for 14-SEP-2013; (b) Map of wind speed modulus merged (m/s) Over UK for 19-DEC-2019.

The minimum WSM occurred within the months of April-june (parts of spring and summer seasons), while the maximum WSM occurred between the months of late November-February (winter season) (Tables 2). The implication of these results is that, the wind speed modulus in the UK is higher in months with the lowest average temperatures (during winter)

Figures 5a & b are the linear regressions of the WSM in London against those of Edinburgh and Manchester, which showed excellent spatial correlations, with R^2 values of 92.14 % and 97.69%

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respectively. The results show a better fit between London and Manchester than London and Edinburgh due to spatial contiguity. The significance of these results is the numerical predictability of WSM in Edinburgh and Manchester using available WSM datasets over London. It should be noted that, Manchester and Edinburg were randomly selected randomly for a test of the spatial correlation in the datasets against those of London only.

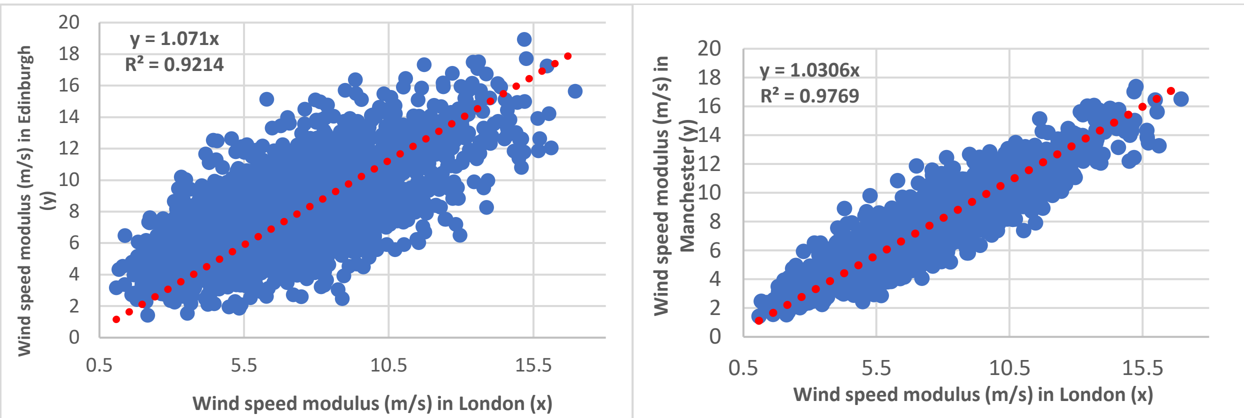

Figure 5a &b: Inter-location WSM correlation between **London** and *Edinburgh*, and *Manchester* respectively.

Table 4 represents the computed dynamic force of wind load on an average vertical surface area of 10m^2 over ten (10) selected locations in the United Kingdom. These computed wind load values are relevant advisory data/information for resilience infrastructure designs, and in particular for wind farm feasibility planning and development in the study area.

Table 4: Measured wind speed and resulting load force on an average vertical surface area of 10m^2 over selected locations in the United Kingdom.

Location	**Wind Speed (m/s)**			**Force of Wind Load (N) ($F_w = ½ \rho v^2 A$) [1 Pa = 1 N/m^2]**		
	Min	***Avg***	***Max***	***Min (F_w)***	***Avg (F_w)***	***Max (F_w)***
London	1.078807	6.939621	16.94314	6.982947	288.95	1722.42
Manchester	1.422003	7.293686	17.37979	12.13256	319.1871	1812.343
Nottingham	1.289207	7.272439	17.46305	9.972328	317.3302	1829.749
New Castle Upon Tyne	1.301466	7.615244	18.57737	10.16288	347.9516	2070.712
Glasgow	1.433846	7.873697	18.84443	12.33549	371.9706	2130.675
Bristol	1.432452	7.088809	16.61599	12.31151	301.5073	1656.547
Cardiff	1.432452	7.088809	16.61599	12.31151	301.5073	1656.547
Norwich	1.161384	7.272558	17.4231	8.092877	317.3406	1821.386
Canterbury	1.010493	6.93141	16.74248	6.126577	288.2667	1681.864
Edinburgh	1.411226	7.826872	18.92371	11.94935	367.5595	2148.641

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Implications of WSM for Engineering Infrastructure

According to [5] infrastructure in the UK experiences significant impacts as a result of the natural variability of climate. These increase in the frequency of severe weather events which will lead to increased disruption of infrastructure and can permanently alter not just the design life-span of infrastructure but also the effectiveness of their functions and services they provide for the society. Wind speed being one of the major climatic variables in modern times must be adequately modelled and integrated into the design and management data of critical engineering infrastructure. The highest range of the force of wind load obtained in this study was about 2149N (2.15kN), recorded in Edinburgh, while the minimum force was about 6.13N(0.006kN) recorded in Canterbury. Monitoring of the wind load on engineering infrastructure is recommended, even when not of a sufficient threat.

The wsm values obtained in this study are not in the class of storm and hurricane; hence considered not inimical or of critical risk and threat to average high-rise engineering buildings and infrastructure in the selected locations across the United Kingdom. The spatial analysis of wind speed therefore forms fundamental advisory information for civil engineering infrastructure design, construction and management. The computed dynamic force of wind load on surface areas of features and space in this study is a vital advisory information for determining the wind impact threshold in the design, construction and management of engineering infrastructure, and in particular for wind farm feasibility planning and development in the study area.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The study evaluated the wind speed modulus over ten (10) selected locations in the United Kingdom. The locations include; London, Manchester, Nottingham, Glasgow, Bristol, Cardiff, Norwich, Canterbury, Newcastle Upon Tyne and Edinburgh. It examined the WSM variability and determined if the values were at the scale of storm or hurricane, or pose critical risk and threat to specific engineering infrastructure in the selected locations across the UK.

In general, the months of April to June (parts of spring and summer seasons) showed a period of minimum WSM, while late November to February (winter season) showed a period of maximum WSM values in the study area. The estimated minimum, average and maximum wind speed values for each location ranged between light breeze (scale 1) and fresh gale wind (scale 8; between 0.5m/s and 20m/s). The average wind speed ranged from 6.93-7.8m/s; hence classified as moderate breeze (5.5m/s - 8 m/s).

On the other hand, the maximum wind speed ranged from 16.9m/s to 18.9m/s; hence classified as fresh gale wind, which can make walking against the wind direction very difficult during its occurrences or event. The WSM values in the study area were therefore not at the scale of storm and hurricane (WSM of 28m/s – over 32m/s); hence considered not of critical risk and threat to average high-rise engineering buildings and infrastructure in the study area.

The highest range of the dynamic force of wind load was about 2149N (2.15kN) recorded in Edinburgh, while the minimum force was about 6.13N (0.006kN) recorded in Canterbury. The computed wind load values in this study are relevant advisory information for resilience infrastructure designs, and in particular for wind farm feasibility planning and development in the study area. The linear regressions of the WSM in London against those of Edinburgh and Manchester showed excellent spatial correlations with R^2 values of 92.14 % and 97.69% respectively, but with a better fit between London and Manchester than London and Edinburgh due to spatial contiguity.

It therefore suffices to conclude that, in view of the emerging relatively unpredictable global climate change phenomenon on one hand, and the benefits of wind speed for wind energy on the other, the spatial analysis of wind speed now forms a fundamental dataset and information for engineering infrastructure design, construction and management.

Recommendations

The study hereby recommends:

i. The inclusion of time series or spatio-temporal analysis of WSM metrics in the design, construction and management of all civil engineering infrastructure in order to mitigate climate change phenomena and enhanced life-span and safety of the infrastructure.
ii. Constant investigation of the phenomenon is recommended to avoid unexpected drastic impact on old and new infrastructure.
iii. The use of the wind speed datasets from multi-mission satellite observation by engineers and infrastructure managers for sustainable wind farm suitability and feasibility study across the UK and other parts of Europe and Africa.

REFERENCES

[1] Abdalla, S., Janssen, P. A.E.M, and Bidlot, J., (2011). On the Accuracy of Surface Wind and Wind-Wave Data. Proceedings of the Tenth International Conference on the Mediterranean Coastal Enviroment MEDCOAST 11, E. Özhan (Editor), 25-29 October 2011, Rhodes, Greece.

[2] Abdalla, S., Janssen, P.A.E.M. and Bidlot, J.R. (2010), “Jason-2 OGDR wind and wave products: monitoring, validation and assimilation”, Mar. Geod., 33(S1), 239- 255.

[3] Bingöl, F. (2009). Complex Terrain and Wind Lidars. Denmark: Technical University of Denmark, 2009.

[4] CNES, EUMETSAT, JPL and NOAA/NESDIS (2011). Ocean Surface Topography Mission/Jason-2 Products Handbook. Issue: 1rev.8- date : December 1, 2011. 72pp

[5] Dawson RJ (ed.), 2015). Infrastructure Climate Change Impacts Report Card 2015. A NERC-Living With Environmental Change (LWEC) Partnership, https://www.ukri.org/wp-content/uploads/2021/12/091221-NERC-LWEC-InfrastructureClimateChangeImpacts-ReportCard2016.pdf

[6] ESRI, 2022. ArcGIS.Pro 3.0. Map. ArcGIS Pro Resources | Tutorials, Documentation, Videos and More (esri.com)

[7] Gu, B., Hao, H., Hui, H., and Xinyu, L., (2015). Calculation Method of Instantaneous Wind Speed Spatial Distribution of Wind Farm. http://dx.doi.org/10.3991/ijoe.v11i1.4157 . iJOE – Volume 11, Issue 1, 2015. Pp. 29-34

[8] http://ddo-aviso.vlandata.cls.fr:41080/thredds/dodsC/dataset-nrt-global-merged-mwind.

[9]http://gyre.umeoce.maine.edu/data/gomoos/buoy/php/variable_description.php?variable=wind_2_speed

[10] Krishnamurthy, R., A. Choukulkar, R. Calhoun, et al. (2012). Coherent Doppler Lidar for Wind Farm Characterization. Wind Energy, 2012, 16(2):189-206. http://dx.doi.org/10.1002/we.539

[11] Li, G. and Shi, J., (2010). On comparing three artificial neural networks for wind speed forecasting. Elsevier: Applied Energy, Vol. 87, Issue 7, July. Pp.2313-2320. https://doi.org/10.1016/j.apenergy.2009.12.013

[12] Sun, S., Qiao, H., Wei, Y., Wang, S., (2017). A new dynamic integrated approach for wind speed forecasting. Elsevier: Applied Energy, Vol. 197, 1 July, Pp. 151-162. https://doi.org/10.1016/j.apenergy.2017.04.008

[13] Ojigi, M. L. and Faloranmi, J. A. (2022). Satellite Altimetry-based Sea Level Anomalies Over Selected Tide Gauge Stations in Nigeria. 3rd NASGL AGM/Conference. Theme: Innovations in Surveying and Mapping Technologies for Earth Systems and Resource Monitoring & Management at Prof. Ajayi Boroffice Conference Centre, NASRDA Abuja. 28-31 March, 2022

[14] Ojigi, M. L. and Opaluwa, Y.D. (2019). Monitoring atmospheric water vapour variability over Nigeria from ERA-Interim and NCEP reanalysis data. *SN Appl. Sci.* **1,** 1159. https://doi.org/10.1007/s42452-019-1177-x (published online 05 September).

[15] Ojigi, M. L., Bawa, S., Youngu, T. T., Moses, M., Azua, S., Aliyu, Y. A., Ahmadu, A. A., and Ibrahim, U. S., (2019a). Modelling Sea Level Anomalies in the Gulf of Guinea from Multi-Mission Satellite Radar Altimetry. Nigerian Journal of Geodesy. Vol.3/1. Dec. 67-76. ISSN 2651-6098.

[16] Ojigi, M. L., Dodo, J.D. and Opaluwa, Y. D., (2019b). Satellite Altimetry-based Significant Wave Height Monitoring of Some Proposed Jetties in Nigeria Coastal Waters. Nigerian Journal of Geodesy. Vol.3/1. December. Pp.7-15. ISSN 2651-6098.

[17] Vignudelli, S., Kostianoy, A.G., Cipollini, P., Benveniste, J. (eds), (2011), “Coastal Altimetry”, Springer-Verlag Berlin Heidelberg, doi:10.1007/978-3-642-12796-0, 578 pp.