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Studies of Windshear Profiles and Turbulence Intensityfrom ObservationsDoppler Sodarover Ile-Ife

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Abstract

Acoustic sounder data have been used to study the windshear patterns and the structures of atmospheric turbulence intensities over Ile-Ife (located on lat.7.29ºN, long. 4.34ºE), a tropical station in Nigeria. Data for 50m and 200m levels were selected and analyzed in terms of local values for u* (friction velocity) and the monin-obukhov length (L). Time evolution of turbulence intensity for both levels was studied. Also, non-dimensionalized standard deviation of the wind fluctuations σ_u/u, σ_v/u and σ_w/u (longitudinal, lateral and vertical velocity components respectively) were computed. The primary focus of this paper is to map out the atmospheric stability in the boundary layer over Ile-Ife. Windshear profiles and turbulence Intensity were analysed to study the practical implications. The study revealed that the non-dimensionalized standard deviations of the wind fluctuations are independent of the stability (z/L) whereas, turbulence intensities ($\frac{\sigma_u}{\bar{u}}$) values are found to depend on the height. It was further showed that high values of windshear are observed at 400m level and above. The practical implications of the results obtained on aviation industry, agriculture and other areas of life were subsequently discussed.

Nomenclature:
Φ^o - Mean Wind speed
z/L- Stability
u^*- Friction Velocity (ms^{-1})
L- Moni-Obukhov length (m)
$\bar{u}$ Mean Wind Speed
$\frac{\sigma_u}{\bar{u}}$ - Turbulence intensity
$\frac{\sigma_u}{\bar{u}}$ -Normalized Standard deviation of the longitudinal Velocity component
$\frac{\sigma_v}{\bar{u}}$-Normalized Standard deviation of the lateral Velocity component
$\frac{\sigma_w}{\bar{u}}$-Normalized Standard deviation of the vertical Velocity component.

1.0 Introduction

To understand and predict significant atmospheric phenomena such as convection and turbulence, certain criteria for determining the stability and vertical moving air must be established [1]. Turbulence intensity is defined as the ratio of standard deviation of the fluctuations to the local wind speed value. The main effect of the turbulence is to cause enhanced diffusion of matters, heat and momentum. The turbulence, which is present in the boundary layer, endows the airflow in the regions, which the necessary elements of conductivity required to maintain essential vertical fluxes of vapour, sensible heat and pollution [2].

However, the dearth of basic data of turbulence fluctuations and related information limit full appraisal of the energy spectral of the longitudinal, lateral and vertical components in most of Nigerian meteorological stations. This is sequel to the lack of instrument to measure directly, the turbulence intensity and related parameters. Information on windshear profile and turbulence fluctuations are of vital importance for activities such as air quality studies, boundary layer studies, windshearobservations in the airports. Windshear profiles and turbulence intensity parameter also enhance full appraisal of the energy situations in Nigeria.

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AdedokunandVanghan [3] reported on the SODAR (Sound Detection and Ranging) research efforts initiated at the ObafemiAwolowo University (O.A.U) Ile-Ife, Nigeria in 1988, to conduct SODAR Doppler wind measurement over Ile-Ife. Since then, the system has accumulated several years of sounding data at the station. The study arose as a result of existence of little information on both wind and turbulence fluctuations over the regions.

The turbulence in the stable boundary layer is characterized by the frictional velocity (U) given by Singal[4] as

$$U_*^2=\tau/\rho=-U'\omega' \qquad (1)$$

Where τ is the surface stress, ρ is the density, U' and ω' are the fluctuations in the horizontal and vertical wind velocities respectively. Evidences supporting the use of equation (1) had been reported by various authors and researchers [1-5].

The main objectives of this paper are to map out the associated atmospheric stability in the boundary layer and to validate the applicability of the remote SODAR system in monitoring the depth of the boundary layers. Also, analyses ofwindshear profiles and turbulence fluctuations were carried out; and to study the practical implications of the results obtained.

2.0 Experimental Methods/Procedure

The SODAR research efforts were initiated by Adedokun, J.A. at ObafemiAwolowo University (O.A.U), Ile-Ife in 1988. Since then the system had accumulated several years of sounding data. Therefore, the data used in the present study were adopted from accumulated data obtained from sensitron SODAR system version 325 whose antennas were mounted on the roof of a 20m building at O.A.U Ile-Ife, Nigeria. Salient features of the system include 150W pulse power, 23KHZ tone pulse frequency, pulse repetition rate of 1 per 7 seconds, and a receiver bandwith of ±150Hz.

The measurements were made during the period of May and June, 1991 under neutral conditions. The height z used in the computations is the effective height that is the physical height less than zero displacement. The mean height of the buildings andthe surrounding vegetation are used to estimate of the zero displacement height.

3.0 Results and Discussion

The turbulence, which is generally presented in the planetry Boundary Layer (P.L.B), endows the airflow in these regions with the necessary element of 'conductivity' required to maintain essential vertical fluxes of water vapour, sensible heat flux and pollution [2]. As a result, the data used have been analysed in term of local values for friction velocity (u_*) and the Obukhov length (L).

Non-dimensionalized standard deviations of the velocity components (longitudinal, lateral and vertical) and related parameters were calculated for selected 50m and 200m levels as shown in Table (1) and (2) respectively.

Table 1: Calculated Values of Mean wind direction, Friction Velocity, Stability and turbulence intensity for z=50m Level.

Local Time(Hr)	(Φ^o)	u	u_*	$\frac{\sigma_u}{\bar{u}}$	$\frac{\sigma_v}{\bar{u}}$	$\frac{\sigma_w}{\bar{u}}$	$\frac{\sigma_u}{\bar{u}}$
12.04am	62.9	0.42	0.29	3.24	2.72	2.48	2.24
12.34pm	67.7	0.37	1.02	0.95	0.81	0.82	2.62
1.04pm	85.2	0.29	0.14	7.36	7.43	11.43	3.55
1.34pm	73.6	0.21	1.29	0.85	0.80	0.73	5.04
2.04pm	0	0.44	0.46	2.09	1.11	1.87	2.18
2.34pm	62.1	0.32	-0.01	-100	-58.0	-82.0	3.13
3.04pm	56.5	0.50	0.53	1.55	0.85	1.58	1.64
3.34pm	54.0	0.39	0.49	2.08	0.84	1.30	2.62
4.04pm	67.5	0.41	0.85	1.22	0.60	0.75	2.54
4.34pm	71.6	0.51	0.94	1.05	0.54	0.73	1.94
5.04pm	33.8	1.01	0.60	1.35	1.00	1.12	0.80
5.34pm	26.0	1.17	0.61	1.66	1.21	1.26	0.86

Table 2: Calculated Values of Mean wind direction, Friction Velocity, Stability and turbulence intensity for z=200m Level.

Local Time(Hr)	(Φ^o)	u	u_*	$\frac{\sigma_u}{\bar{u}}$	$\frac{\sigma_v}{\bar{u}}$	$\frac{\sigma_w}{\bar{u}}$	$\frac{\sigma_u}{\bar{u}}$
12.04am	-1.0	1.41	0.29	3.31	9.30	1.41	0.68
12.34pm	3.50	3.93	1.02	0.93	2.74	0.57	0.24
1.04pm	63.6	0.76	0.14	5.35	16.5	2.21	0.99
1.34pm	12.1	4.52	1.24	0.85	2.38	0.37	0.23
2.04pm	0	2.04	0.46	2.76	6.26	1.26	0.62
2.34pm	78.9	0.29	-0.01	-88	-189	-	3.03
3.04pm	57.4	2.32	0.53	1.60	5.64	1.66	0.36
3.34pm	36.0	2.08	0.49	1.92	5.45	1.33	0.45
4.04pm	12.3	3.34	0.85	1.02	3.28	0.85	0.26
4.34pm	11.4	3.76	0.94	0.85	2.26	0.54	0.21
5.04pm	16.3	3.11	0.60	1.40	3.87	0.82	0.27
5.34pm	16.0	3.27	0.61	2.56	2.66	1.13	0.4

For the constant flux layer, the moninobukhov similarity theory offers a good basis for the analysis of turbulence characteristics [1], In practical form, the local values for moninobukhov length (L) were calculated using the relation according to [2];

$L= -u_*^3T_o^2/gk\omega'\theta'$ (2)

Where $\omega'\theta' = H/(\rho c_p)$ (3)

The basis parameter in equation (1) was determined from the relation

$U_*= k \{(u(z_2)-u(z_1)\}/ \ln (z_2/z_1)$ (4)

Where $T_o$is the local mean temperature, g is the acceleration due to gravity, k is the Von Karman constant with a standard value 0.40; ρ is the density of the air parcel and $c_p$is the specific heat capacity at constant pressure.

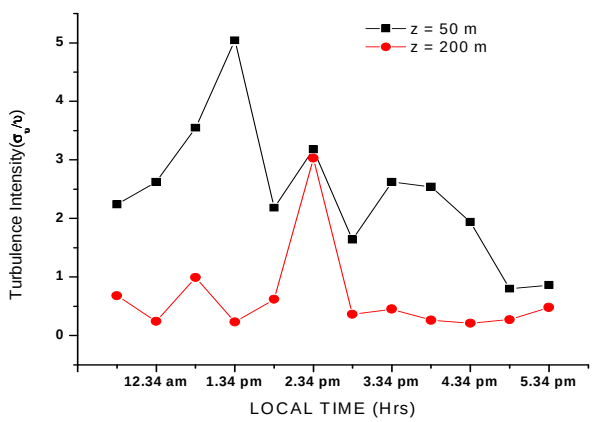

Fig. 1: The profile of time evolution of turbulence intensity ($\frac{\sigma_u}{\bar{u}}$) for 50 m and 200 m levels

Fig. 1 shows the profile of time evolution of turbulence intensity ($\frac{\sigma_u}{\bar{u}}$) for 50m and 200m levels. At 50m level, the turbulence intensity ranges between 0.80 and 7.00. While at 200m level turbulence ranges between 0.30 and 3.00. The curve shows similar trend from 12.00am to 2.00pm when there was drastic change in the turbulence intensity between 2.00pm and 3.00pm. Therefore, turbulence intensities are found to depend on height in a manner, which indicates a simple similarity relation to apply. The highest value for turbulence intensity (5.0) was foundat around 1.30pm for 50m level. For 200m level, the highest value was 2.50, which fell around 2.30pm.

The analyses show that the non-dimensionalized standard deviations of the wind fluctuations are independent of the stability (z/L). Although, the values obtained for 50m level are slightly due to non-equilibrium condition between 1.00pm and 3.00pm. The analyses prove further that the longitudinal, lateral and vertical components with respect to $u_*$and L are found to be in good agreement with results got byHogstrom [1] at two cities of Uppsala, Sweden under neutral conditions.

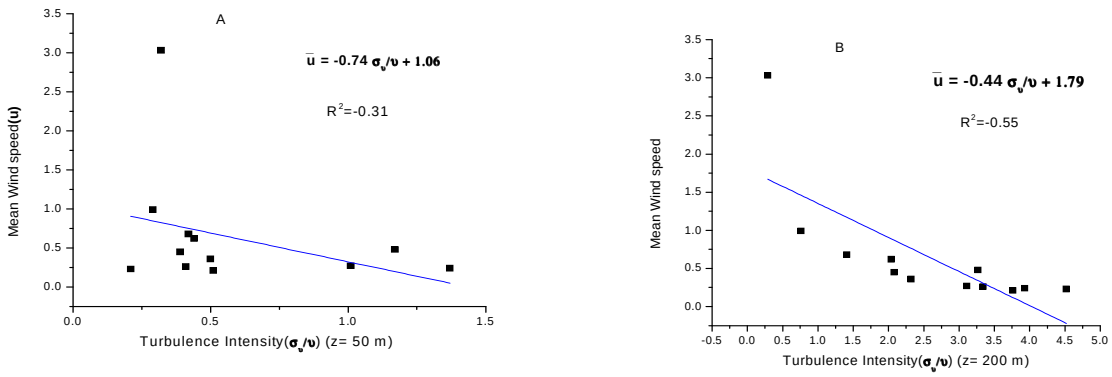

Fig. 2: Comparison of the turbulence intensity for both 50m and 200m for the station.

Generally the study revealed that the windshear was relatively high at 200m level and above. This result is in good agreement with the results got byAdedokun and Holmgren [5]. This result is an indication of energetics of the eddy circulations, which may be associated with gravity wave activity in the environment.

4.0 Practical Implications of the Results Obtained

This study attempts to summarize and to generalize the findings in a manner suitable for practical applications. The information presented is found useful in practical applications such as wind load analysis, boundary layer studies, and wind shear studies and air quality pre-evaluation studies.

The shear of the horizontal component of the wind is considered to be of significance to convective systems in the boundary layer. Neff and Coulter [6] affirmed that if the vertical shear is greater than 0.1 per second in the lower 100m, it is dangerous to large swept wing and jet-powered aircraft. All these information are of great value in relation to calculations of dispersion of air pollutants. Furthermore, the variance of the vertical velocity for extended time periods can be related to coefficient for the vertical diffusion.

5.0 Summary and Conclusion

It has been generally observed that there is dearth of data on windshear and turbulence intensities both in meteorological stations and in research institutes. This is sequel to lack of relevant instrument.

Based on this, the study tries to analyse, using acoustic sounder data, windshear profiles and turbulence fluctuations so as to study the practical implications of the results obtained. The findings indicate that a particular similarity might be applied in the neutrally stratified atmosphere. There were more or less rapid variations of the shearing stress with height as shown in the figures. The major factor that may affect the variations is due to the coriolis force, though it is negligible close to the ground but increases gradually with height. The shear of the horizontal component of the wind considers being of significance to convective system in the boundary layer.

The results in the paper are indication of the energetics of the eddy circulations associated with gravity wave activity in the environment. It is hoped that the work be extended to other stations so as to investigate the spatial variations of windshearand turbulence intensities within Nigeria.

6.0 References

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