Investigating Wind Shear Characteristics at 50m Meteorological Tower

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ABSTRACT:*Wind measurement is important for estimating wind energy potential but relatively cost-intensive and often conducted at a narrow height near or not far from the ground at the typical range of most wind hub heights in current wind turbine technology is 30-50 m (or even higher). Extrapolation on wind data thus becomes necessary to estimate wind speed at a high altitude. Doing so requires the essential understanding of wind shear characteristics representative to a location or a region. The analysis is carried out from the profile of meteorological data collected from 50m tower at Sathyabama University during the year 2010-2014. The tower is located near the coastal region in Chennai. The tower is equipped with instruments to measure several meteorological variables. For wind speed and direction, they are routinely measured at different heights, which are considered well suitable for wind shear characterization. In this work, the characteristics of wind shear exponent at the tower were investigated and discussed, with emphasis on temporal (diurnal and monthly) variation and occurrence distribution.*

Keywords: Wind Energy, Wind Shear, Surface Roughness, Meteorological Tower

Received: 3 June 2017, Revised 25 July 2017, Accepted 29 July 2017

1. Introduction

Wind power has received continued interest worldwide for the reasons that it is abundant and clean (i.e., non-polluting) and that its utilization does not contribute to global warming. Wind energy development has been active and continued in Tamil nadu. The effective and successful development of a wind energy program depends significantly on the availability of winds. Thus, the wind resource of an area or a region of interest for wind energy application needs to be assessed. Various methods of wind resource assessment have been proposed, ranging from measurement methods to computer simulation techniques (Landberg2003). Measurement methods are straightforward and desirable but relatively cost-intensive. Wind Resources and Environment, Tamil nadu, has been established measurement is often conducted at a limited height near or not far from the ground (i.e., 2-10 m) while the range of most wind turbine hub heights in current wind turbine technology is 30-50 m (or even higher). Several meteorological and wind monitoring programs are present in Tamil nadu and operated or owned by governmental and non-governmental

(Farrugia2003]. However, most of them are limited to near-ground measurement.

Analyzing the relationship between the environment and the atmosphere on a local scale is complicated on a meso-scale. The sea breeze is a meso-scale occurrence (Oke2005) precise to coastal environment. The local vegetation and aerodynamic characteristics on land surface directly affect the transport of energy and substances between land surface and atmospheric boundary layer. Therefore the subject of every kind of process on land surface becomes essential (Stull, 1988; Weingara 1993; Masao, 1997). Atmospheric boundary layer and surface parameters are mostly important in air pollution dispersion analysis. Many pollution sources and their dispersion come about within the roughness surface layer in the lower atmosphere. The roughness length is essential in determining wind shears over a surface and manipulating mechanical turbulence development. A huge roughness length increases surface friction and this increases vertical turbulent mixing and wind shear.

In case of lack of wind measurement at a high level, extrapolation of wind speed measured near the ground is often made, which typically use the following well-known power-law wind profile relationship (Rehman2005)

$$U2/\,U1 = (Z2/\,Z1)^{\alpha} \text{ or } \alpha = \ln(U2/\,U1)\,/\,\ln(Z2/\,Z1) \qquad (1)$$

Where U1 and U2 are the wind speeds at heights (above the ground) Z1 and Z2, respectively, α is the wind shear exponent or coefficient (shortly, the shear exponent), and in is the natural logarithm. A typical value of 1/7 (or ~0.14) for á is often adopted when no recommendation for other specific values is available.

The relationship in Eq. (1) with $\alpha = 1/7$ is customarily called the $1/7^{th}$ power law, and it generally well describes wind profiles within 50 m above the ground for near-neutral conditions (Gryning 2007)

In Tamil nadu, to the author's knowledge, there has not been much investigation of wind shear characteristics. The 50m instrumented meteorological tower is located in Sathyabama University which is located in the coastal areas of Chennai. The primary objective of this tower monitoring program is to provide long-term meteorological data in the lower atmosphere at heights up to 50 m (above the ground) to support air quality management. Each tower is equipped with various instruments to measure several meteorological variables, which are wind speed and direction, temperature, humidity, radiation, and rainfall. Wind speed and direction are measured using at three different heights (2,8,16,32, and 50 m), which is considered well suitable for wind shear study. An example of wind shear study using data from tall towers can be seen in Schwartz and Elliott (Schwartz 2006). In this work, the characteristics of the shear exponent for each station were investigated, with emphasis on temporal (diurnal and monthly) variation and overall occurrence distribution.

2. Methodology

Five years (Jan., 2010 - Dec., 2014) of ten minutes wind data from the tower is obtained and used in the investigation here. Eq. (1) was employed to determine the shear exponent. The quality of wind data measured at 50m, 32m, 16m, 8m, and 2m were considered and screened were good and reliable. This is believed to be caused by disturbances from structures or objects on the ground. The following rules were applied in screening as part of data quality checking:

- Speed at 32m < Speed at 50m
- Speed at 16m < Speed at 32m
- Speed at 8m < Speed at 16m
- Speed at 2m < Speed at 8m
- Difference of direction at 32m and direction at 50m < 45 degree
- Difference of direction at 16m and direction at 32m < 45 degree
- Difference of direction at 8m and direction at 16m < 45 degree
- Data at ten minutes interval with no missing values on both speed and direction

2.1 Determination of Wind Shear

The main objective of this paper is to identify the vertical wind shear models and procedures that decreases the uncertainty correlated with wind shear analysis. Measuring a wind shear using remote sensing and tall wind turbine sites are more expensive than an instrumented meteorological tower. In the estimation of wind resources, the use of wind shear models added with uncertainty. The most commonly used methods of estimating wind shear are known as the log law and the power law. The surface roughness length is a parameter used to characterize shear and is also the height above ground level where the wind velocity is zero.The surface roughness length varies according to the terrain of the location and normally use surface roughness lengths close to those provided in the Table 1. The Power law exponent values for different types of terrains are listed in Table 2.

Terrain Description	Surface Roughness Length, zo (m)
Very smooth, ice or mud	0.00001
Calm open sea	0.0002
Blown sea	0.0005
Snow surface	0.003
Lawn grass	0.008
Rough pasture	0.01
Fallow field	0.03
Crops	0.05
Few trees	0.1
Many trees, hedges, few buildings	0.25
Forest and woodlands	0.5
Suburbs	1.5
Centers of cities with tall buildings	3.0

Table 1. Surface roughness values for various types of terrain

Terrain Description	Power law exponent, α
Smooth, hard ground, lake or ocean	0.10
Short grass on untilled ground	0.14
Level country with foot-high grass, occasional tree	0.16
Tall row crops, hedges, a few trees	0.20
Many trees and occasional buildings	0.22 – 0.24
Wooded country – small towns and suburbs	0.28 – 0.30
Urban areas with tall buildings	0.4

Table 2. Power law exponent values for different types of terrain

2.2 Wind Shear Analysis

The wind speed measured at heights 2, 8 and 16m were referred as the lower heights. The wind speed data at 32m and 50m are the highest levels compared to the lower levels.

2.2.1 Vertical Wind Speed Profile

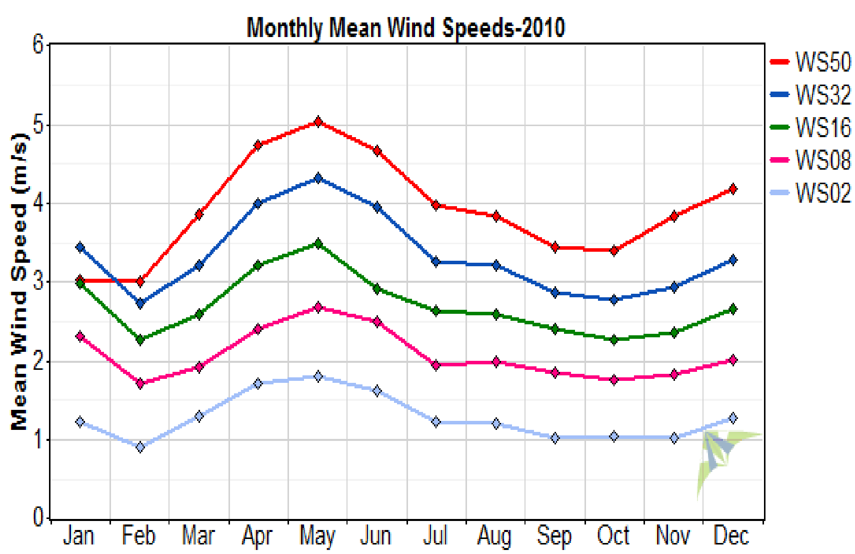
The atmospheric surface layer closest to the earth, in general whose height normally ranges from 2-2000 m above the ground is influenced by contact with the earth's surface. The lowest 10% of the atmospheric boundary layer, called the surface layer is where turbulence and friction drag from the ground are the most considerable effects (Huschke, 1989). The surface layer of the ABL has been broadly studied due to its ease of access and significance, as all human being life resides in this layer. The studies observed on these characteristics were often reliable and were used to form the basis of the similarity theory principles that are used today in defining the characteristics of vertical wind profiles within in ABL (Stull, 1988). Precise scaling relationships (such as the Monin-Obukhov similarity theory) were developed for the surface layer and consequently verified to be accurate when the winds are not calm, and in heights between 10-200 m above ground (Panofsky et al., 1977). These resemblance relationships began to function as the groundwork for the scientific study of the most important feature of the surface layer for wind energy developers and air quality managers. Two types of models are most extensively used in practice: the logarithmic and the power law models.

2.2.2 Surface Roughness Length

Over most natural terrain, the surface cover is not uniform and changes significantly from location to location. While atmospheric pressure gradient forces are the major control of wind speed and direction in the ABL, winds near the ground are heavily influenced through frictional drag imposed by surface roughness (Oke,1987). This frictional drag cause's turbulence, giving rise to a sharp decrease in wind speed as the underlying surface is approached. The height at which this frictional drag influence is felt is related to the size and distribution of the underlying surface elements. Theoretically, z0is defined as the height in meters above the ground level in which the mean wind speed becomes zero when the logarithmic wind speed profile extrapolated downwards through the surface layer (Huschke, 1989). As z0 is observed to increase with the average height and spacing of individual elements of the ground cover, such as trees or houses, it is often defined in this fashion (Jackson, 1980). An alternative but related definition suggests that z0 is the size of turbulent eddies on the ground surface created when winds are disrupted by items on the surface; where larger z0 values indicate larger eddy mixing, and likely larger surface objects (Panofsky and Dutton, 1984).

Roughness length has usually been estimated for local sites from vertical wind profiles and micrometeorological theory. The wind speed increases as the height increases. The frictional forces play a significant role when dealing with wind velocity profile even though they were caused by the surface layer of the earth which is called roughness length. Logarithmic profile is the common profile to represent wind speed in atmospheric boundary layer. The influence of z0 on the logarithmic wind profile is significant. When z0 is small, the wind profile increases rapidly with height over a short length, and then is relatively stable above that height. When z0 is large, the profile has a slow and smooth increase with height (World Meteorological Organization, 1981).

3. Results and Discussion

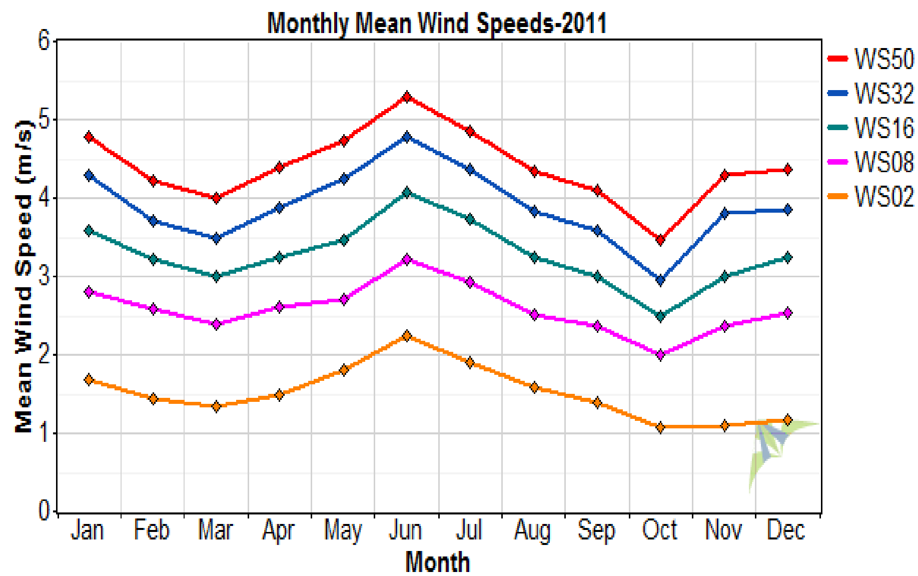


(a)

This section provides detailed monthly mean wind speed, Cumulative distribution function, Vertical wind shear profile and surface roughness at 2, 8, 16, 32 and 50 meters for the year 2010-2014.

3.1 Monthly Wind Speed Profile

The monthly mean wind speed analysis carried out for five years from 2010-2014 at all levels from ABL and depicted in Figure 1(a-e). In the year 2010 the mean wind speed, gradually increases from February to May and reduces up to October. The highest mean wind speed of 5 m/s occurs in the month of May in the 50m level. In 2011 the highest mean wind occurs at the month of June. The wind speed gradually decreased from January to March and then increasing. From June to October it decreases. The mean wind speed has the value of 4 m/s in March in 2012 and suddenly reduces to the month of Aprils and gradually increases. In October month the wind speed increased up to 4.5 m/s. From January to June the wind speed increased from low level of 3/ms to the highest wind speed occurs at 5 m/s after that it is reduced to lower speed. The wind speed of 5.2 m/s occurs has the highest in the month of July in the year of 2014 and gradually decreases after that.



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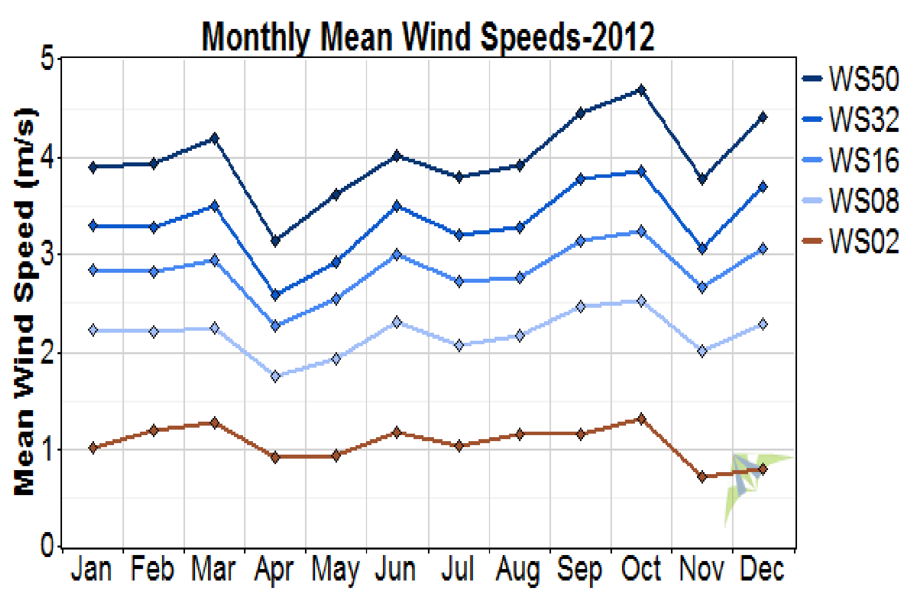

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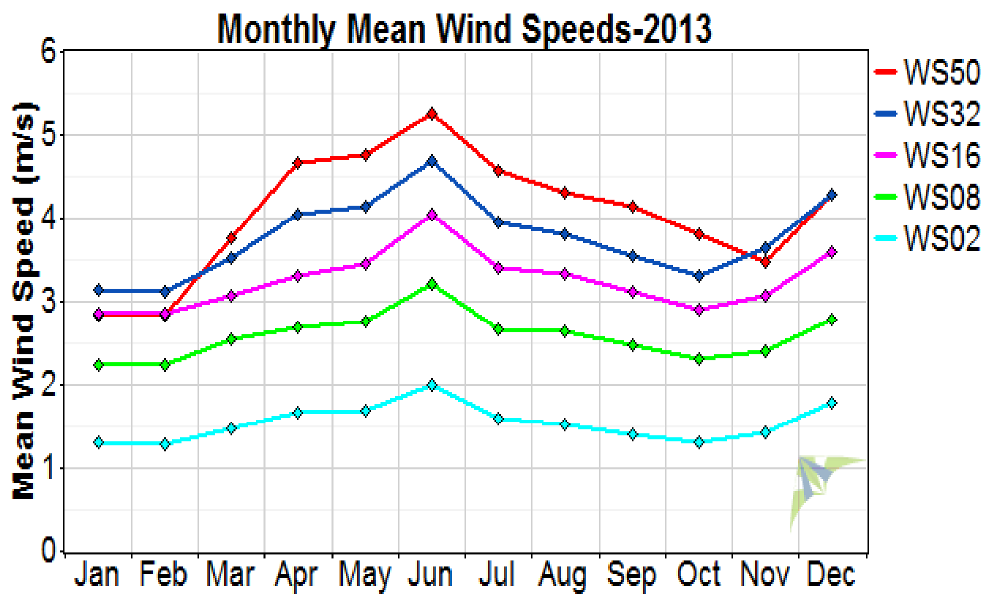

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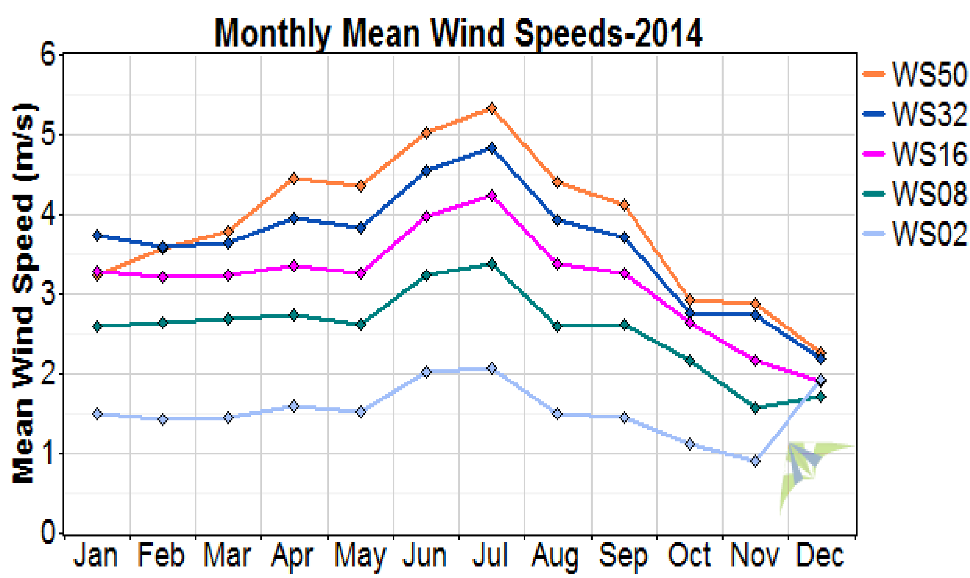
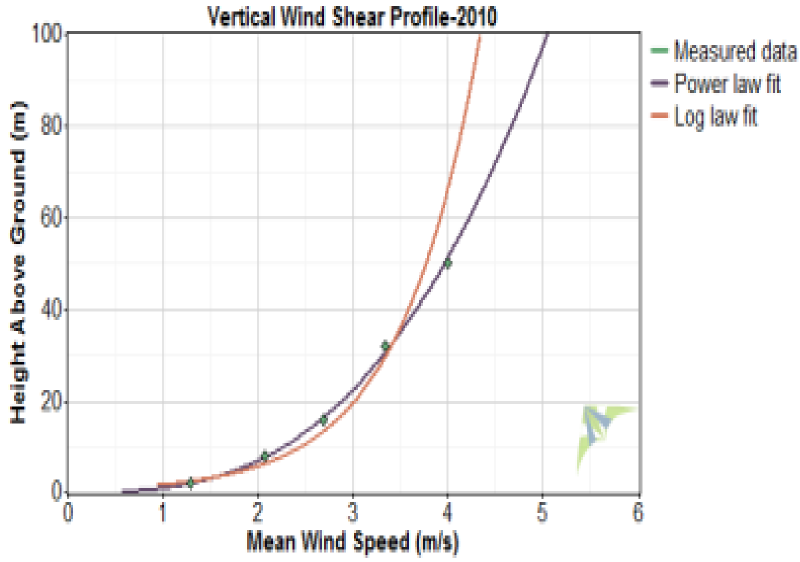


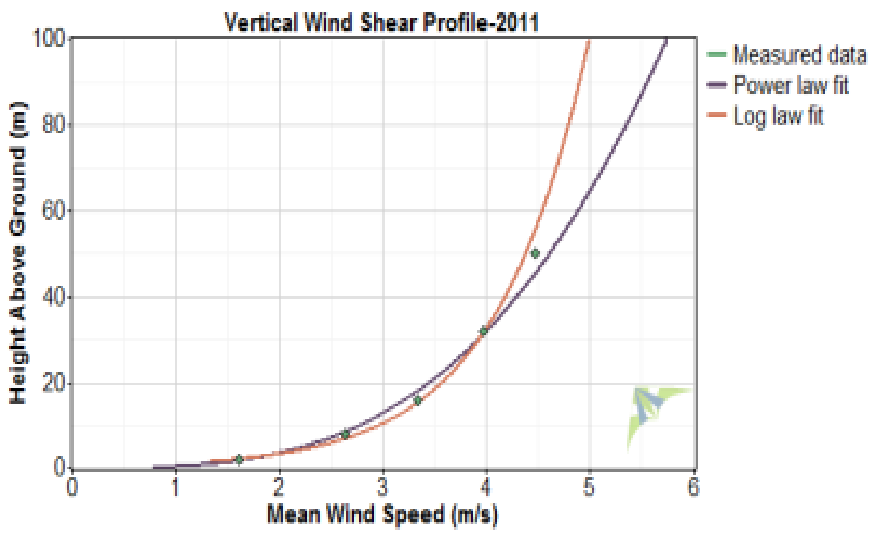
(e)

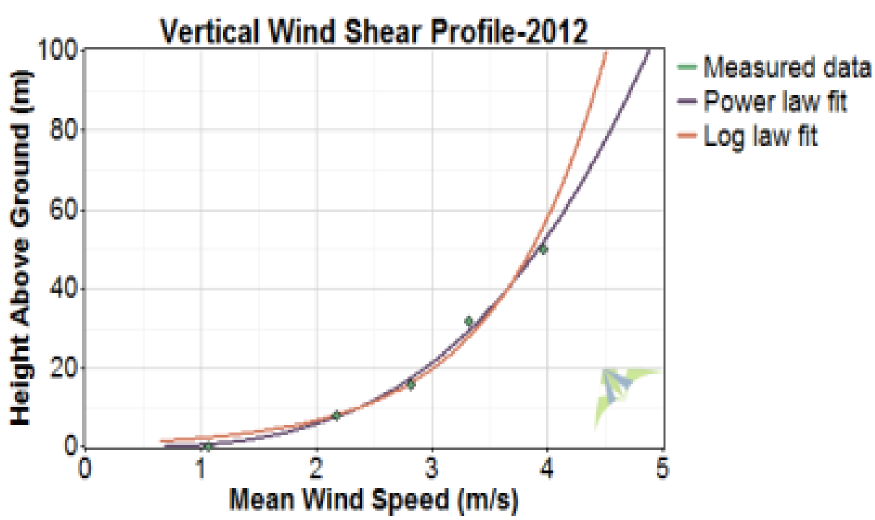
Figure 1. Monthly Wind Speed profile

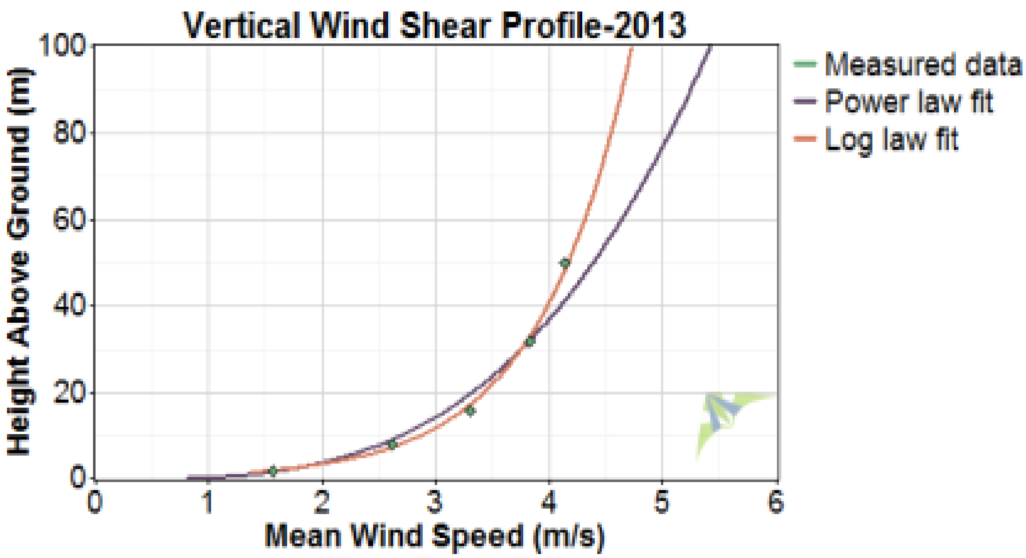
3.2 Vertical Wind Shear Profile

For extrapolating the energy resources the power law and large law proved to be preferable at different heights. Power law exponents or logarithmic fits differ in wind speed profiles and there is an uncertainty, according to the hub-height wind speeds of lower height anemometer data. The power law exponents vary by function of location, time and other factors. In this study the power law and the log law exhibit a good accuracy for roughness and shear coefficient and have the same certainty as shown in Figure 2. The shear parameter is dependent on atmospheric stability and ideally determined in different atmospheric regimes. The wind shear is near to a typical power law exponent value. Shear exponents developed from five years of data are applied to determine the robustness of the power law method.


Vertical Wind Shear Profile-2010
Height Above Ground (m)
Mean Wind Speed (m/s)
Measured data
Power law fit
Log law fit


Vertical Wind Shear Profile-2011
Height Above Ground (m)
Mean Wind Speed (m/s)
Measured data
Power law fit
Log law fit


Vertical Wind Shear Profile-2012
Height Above Ground (m)
Mean Wind Speed (m/s)
Measured data
Power law fit
Log law fit



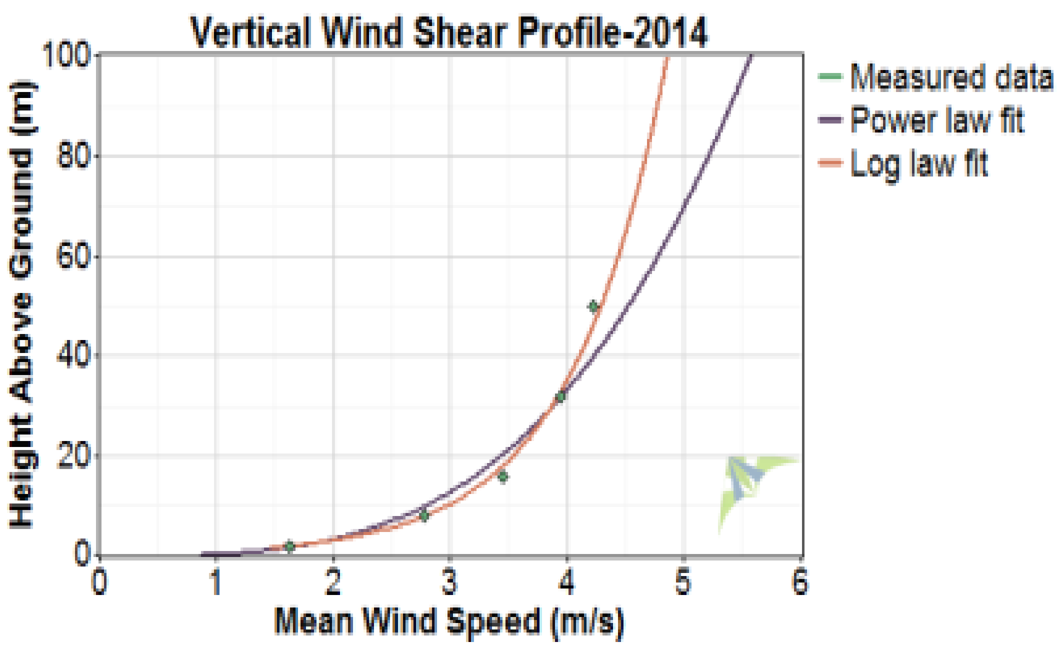


Figure 2. Vertical Wind Shear Profile

3.3 Surface Roughness

Frictional forces act as an important role in wind speed profile. The frictional forces are the base in the surface layer of earth which is called roughness length. The general profile to represent wind speed in atmospheric boundary layer profiles is logarithmic profile. Roughness length and wind shear profile for different wind directions for the years 2010-2014 were analyzed over the site(Figure 3). Local meteorological roughness associated with studies conducted using the experimental data obtained with 50m tower. Various factors affected vertical wind shear, either directly or indirectly including roughness, month wise and wind direction. The ground roughness length indicates the degree to which wind is slowed down by friction and it passes close to the ground. The wind is slowed down in rougher ground and the roughness length is large. In this study the roughness length analyzed every month occurs 3 to 4 meters ABL for five years which refers to landscapes with many trees and buildings.

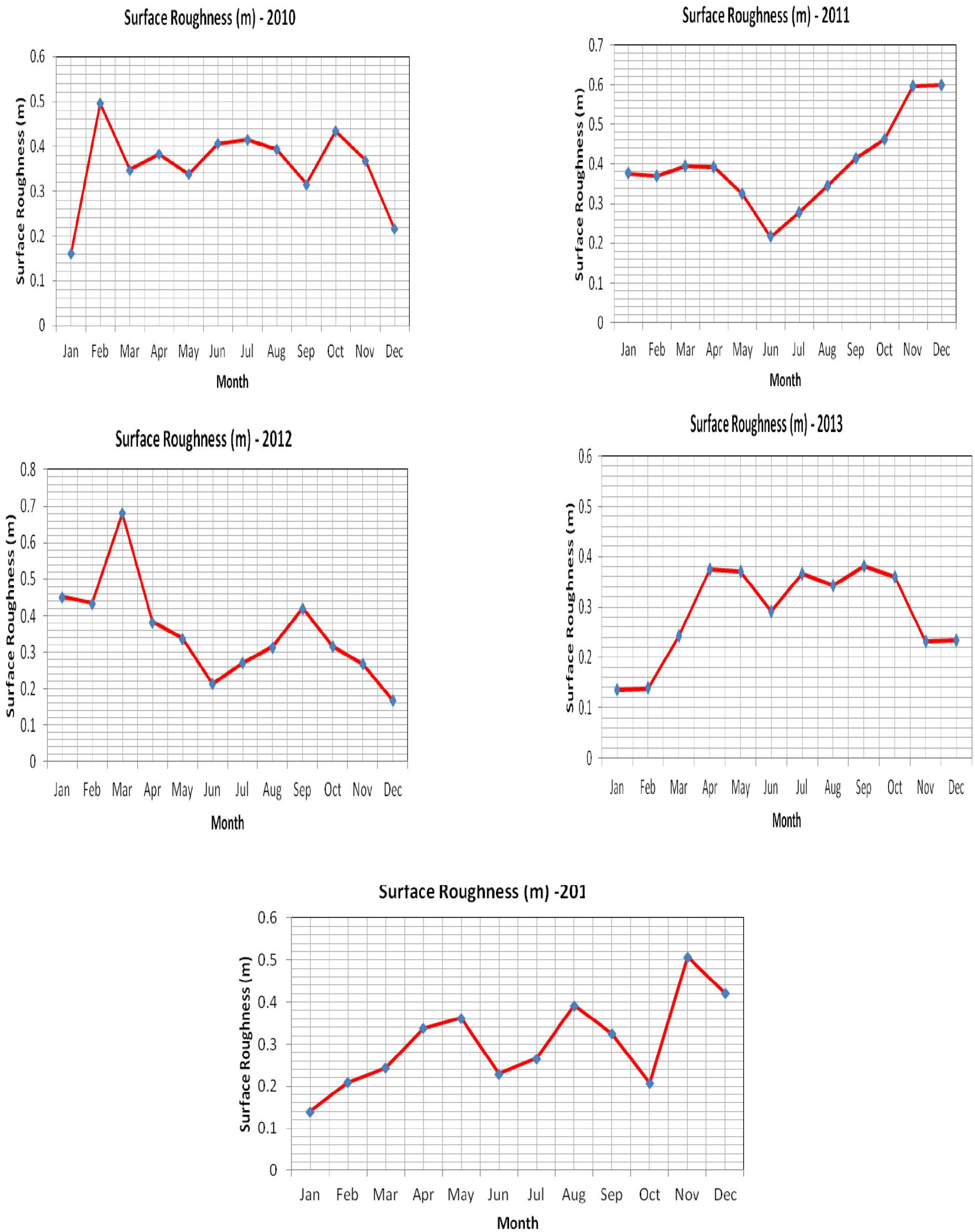


Figure 3. Surface Roughness

4. Conclusion

The work carried on this study near the urban coastal are at Sathyabama University. The wind shear coefficient has been determined and the effect of vertical wind shear on velocity has been analyzed. The power law is a good agreement to the real surface layer wind profile near the coastal smooth terrain. There is a significant influence of land-sea interface shows lower wind shear coefficient during sea breeze conditions than in land breeze. In the month of March to June show higher values of wind shear component, the other months shows lower values. The variation of wind shear with different directional sector emphasized the major role played by the topography and land use. Roughness length is strongly dependent on wind direction, as upstream topographic features are more relevant to local turbulence in horizontal winds, rather than local topographic features. Low and high values are clearly observed during onshore and offshore flows. The characteristics of roughness length and its variation strongly affected in land-sea interface sectors.

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