EXPERIMENTAL INVESTIGATION OF COMPLEX TERRAIN BOUNDARY LAYER WITH A 100mMAST

E.Binopoulos, M.Koulouvari, D.Foussekis, F. Mouzakis

Center for Renewable Energy Sources (CRES)
19th km Marathonos Ave.,190 09 Pikermi, Greece
tel: +30 1 6039 900,fax: +301 6039 905
email: binop@cres.gr

ABSTRACT: The experimental investigation of the boundary layer characteristics at a complex terrain site is performed by the extensive instrumentation and operation of a 100meter mast located at CRES test station at Lavrio. The experimental setup supports wind and meteorological magnitude measurements. The initial data analysis is focused on the description of the basic deterministic and stochastic parameters and their dependency with height. The results comprise a valuable tool for setting the design envelope for wind energy applications in complex terrain.

1 INTRODUCTION

During the recent years research on wind energy applications on complex terrain was intense and consequently major findings related to wind turbine operation were found. Most drammatic of all was the change in the way that the wind inflow was regarded. All the work performed regarded medium sized (at that time!) WTs of 500kW power and hub height of 35m. Evolution of technology, in terms of WT sizing and project implementation, makes nowadays clear that megawatt sized WT will also dominate complex terrain sites.

In this direction, CRES launched an experimental study regarding the description of wind structure in complex terrain at heights that are now relevant to wind energy applications, having as the basic tool the new 100m mast located at CRES test station (figures 1 and 2). In the following paragraphs a brief overview of the experimental setup and results regarding wind structure deterministic and stochastic megnitudes are presented.

The focus of the analysis is located to those items that were found, during previous research projects, as significant to the wind turbine operation ([2], [3]).

Figure 1. North-Eastwards view of the 100meter mast.

2 DESCRIPTION OF EXPERIMENTAL SETUP

2.1 Meteorological mast

The technical characteristics of the meteorological mast are summarised:

Type.......................................triangular lattice, guiwired
Mast height.............................100m
Mast weigth............................13tn
Distance of anchors................48m/65m
Mast projected area.................0.4m^2/m
Projected area coefficient.........0.3 m^2/m^2
Drag coefficient........................0.44 [1]

2.2 Sensors

The sensors used for the experiment are given in the following table:

Signal	Sensor	Make
Wind sped	Cup anemometer	Vector A100K
Wind direction	Vane	Vector W200P
3D wind vector	Sonc anemometer	GILL Windmaster
Temperature & Humidity	Thermo-hygrometer	Vaisala HMP45A
Solar irradiance	Pyranometer	Kipp&Sonen CNR1
Pressure	Barometer	Vaisala PTB100A

Cup anemometers and vanes are positioned at 5 levels, namely 14m, 33m, 55m, 78 and 100m.. Two sonic anemometers and two thermohygrometers are placed at 33m and 78m. Solar and reflected irradiance are measured at 10m whereas air pressure is measured at ground level. Dedicated instrumentation is utilised for signal protection, filtering and conditioning.

The sensors are supported on the mast by the aid of telescopic booms of rectangular cross-section, made of high strength aluminum alloy. Boom cross-section is 50mmX50mm at base and 30mmX30mm at the end where the sensors are supported. All wind sensors are mounted at a height of 45cm aboove the boom and at a distance of 310cm from the outer mast leg [1].

2.3 Data acquisition system

The Data Acquisition System is a PC based system, equipped with a NI card, running under CRESDAQ software. Sampling rates are 1Hz for all signals with the exception of sonic anemometers that are sampled at 8Hz. Data are stored as time series. The system is remotely controlled by SMS messages. Details regarding the experimental setup are found in [4].

3 RESULTS

The analysis procedures followed are those used in EU projects MOUNTURB [2] and COMTERID [3]. The data presented in the following paragraphs were collected within the period from 10/2000 till 6/2001. The data are presented as bin averaged values accompanied by curves that limit the one standard deviation from the mean.

3.1 Deterministic magnitudes

In figure 3 the wind shear exponent for north direction is presented. The values of the exponent were found from a best fit procedure applied to the five cup anemometer recordings. The observed values are consistent (mainly due to the fact that topography do not induce overspeed effects) and describe a flat boundary layer.

Wind inclination at 33m agl is presented also in figure 3 for north as well as for western wind directions. Mean values are low and depend strongly on the wind direction.

3.2 Turbulence magnitudes

In figure 4 the turbulence intensities for the five measured levels are presented as functions of the wind speed (in this case the averaged value from all cup anemometers) for the north wind directions ($-40^o \sim +40^o$). The variation of the turbulence intensity is evident, that is lower values are seen at higher levels. Still at 100m agl TI is 10%. Within the above window of north winds no significant wind direction effects were seen (figure 5 presents TI for wind speed in the range of 9-19m/s). The drop of TI values at high winds is due to the low amount of data in this range.

Reynolds stresses are presented in figure 6 and regard measurements with sonic anemometer at 33m agl. Most significant is the negative correlation of the longitudinal and vertical wind component that results to u'w' values of $-0.8 m^2 s^{-2}$ at high wind speeds.

In figure 7 the length scales at 33m agl are presented. Representative values are 80m, 25m and 15m for Lu, Lv and Lw respectively. On the same graph the lateral and vertical turbulence ratios (σ_v/σ_u, σ_w/σ_u) are presented. The observed values (0.85 and 0.55 respectively) do not present the typical complex terrain high levels. On the same site at the top of the hill, located westwards to the mast (see figure 2, met mast 30m), values of 0.85 and 0.7 were measured at 22m agl.

The dependency of the turbulence and spectral characteristics with height is examined by evaluating the ratios of these characteristics from the measured data at 33m and 78m agl.

In figure 8 the ratios of the diagonal Reynolds stresses are given. The decay of longitudinal turbulence with height is much more pronounced (~50%) that those of lateral and vertical component. The later maintains 80% of the low level values. The above are also reflected in the graphs of the σ_v/σ_u and σ_w/σ_u ratios (figure 8). These ratios are higher at 78m agl, especially for σ_w/σ_u, which in absolute values reaches levels of 0.7.

Length scales are increased at higher levels, as shown in figure 9. Representative increase is 60% for all components.

3 CONCLUSIONS

The experimental investigation of complex terrain boundary layer characteristics within 100m agl reveals important information that is closely related to wind turbine operation.

The presented analysis that focused on wind shear, wind inclination, turbulence structure and wind speed spectral characteristics led to the following that are applicable for complex terrain sites:

- wind shear is flat (fitted exponent values around 0.075); in the cases where topography induces overspeed effects power law cannot describe reliably the variation with height
- high wind inclination is not in general a complex terrain characteristic; especially in cases where top of hills or ridges are considered, inclination may be well close to zero
- turbulence intensity decays slowly with height; a 4% difference is seen between 33m and 100m agl
- length scales, that is Lu,Lv and Lw, are following the ratio 1:0.3:0.2; Lu was found to be around 80m for the north directions
- length scales are increasing significantly with height; from 33m up to 78m agl a consistent increase of 60% for all scales was found
- vertical turbulence ratio (σ_w/σ_u) was found to increase with height, as from 0.55 reaches values of 0.7; although the longitudinal turbulence decays quickly with height, the vertical component still maintains high values

The exploitation of the experimental setup and the collected data will regard the following issues:

- use of data base for complex terrain characterization
- support wind flow simulation model development and validation
- support standardization work
- use of measuring platform and equipment for third-party services

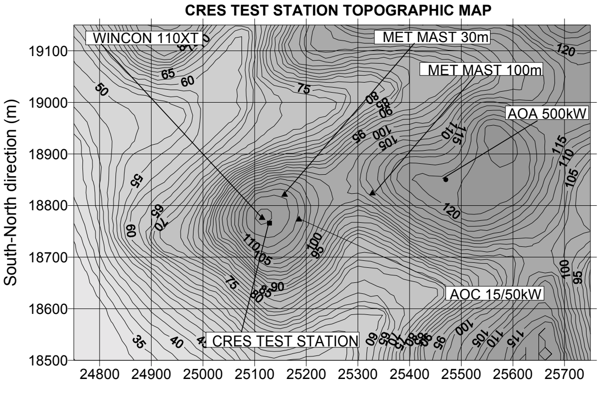

Figure 2. Topographic map of CRES test station.

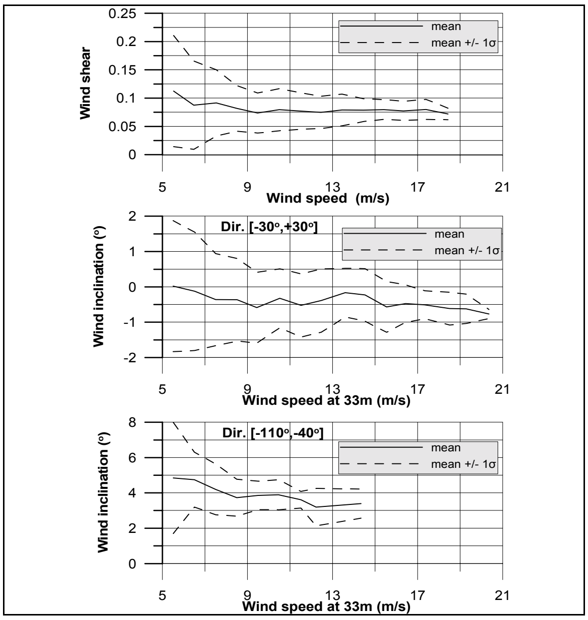

Figure 3. Wind shear and inclination distributions.

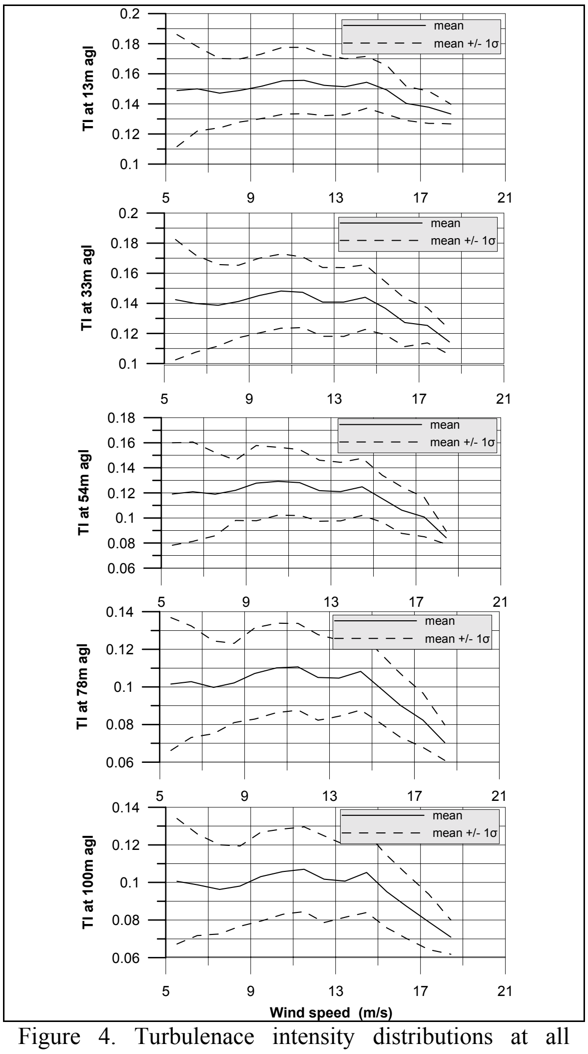

Figure 4. Turbulenace intensity distributions at all heights.

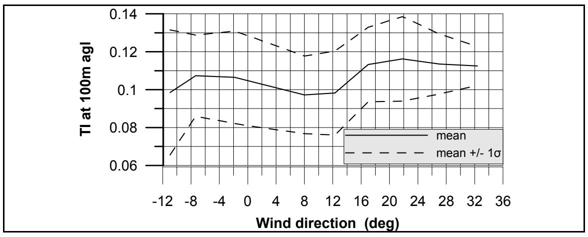

Figure 5. TI at 100m variation with wind direction..

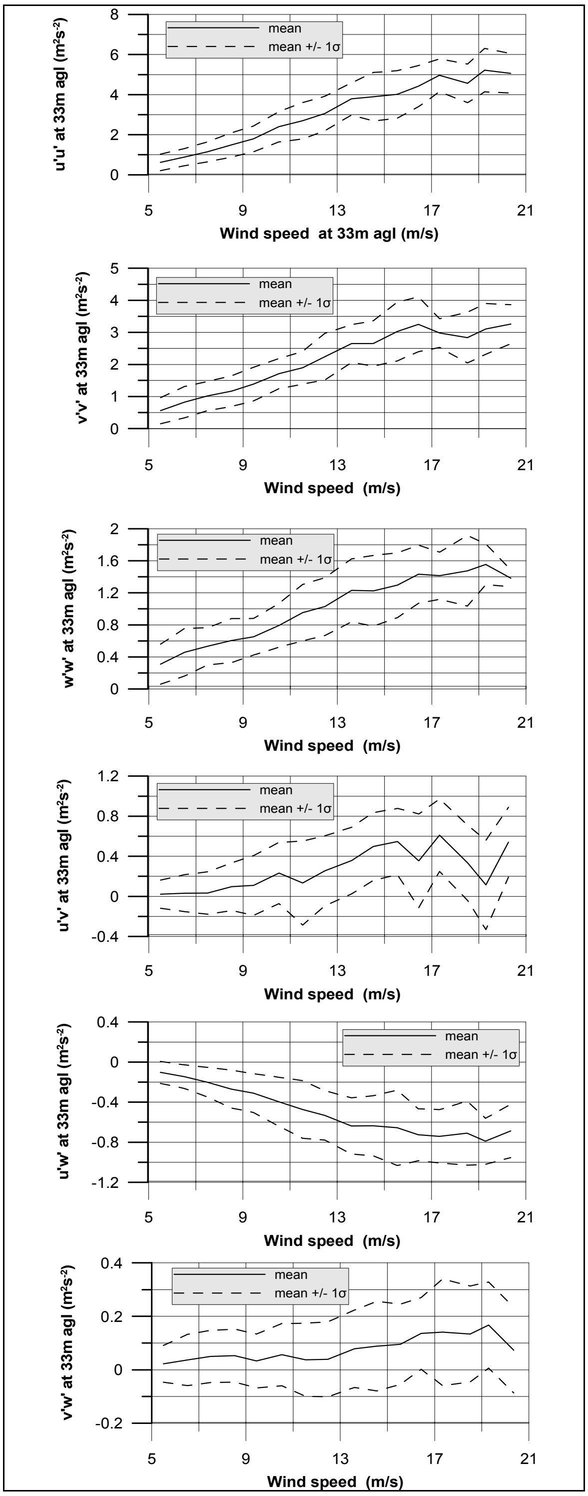

Figure 6. Reynolds stresses distributions at 33m agl.

REFERENCES

[1] “Recommended practices for wind turbine testing“. 11 Wind speed measurements and use of cup anemometry. Ed.1999.

[2] “MOUNTURB, JOU2-CT93-0378 Project“, Final Report, issued by CRES, November 1996.

[3] “COMTERID, JOR3-CT95-0033 Project“, Final Report, issued by CRES, April 1998.

[4] Mouzakis F., Koulouvari M.: “Experimental investigation of atmospheric boundary layer on the 100m mast“, CRES Internal report, December 2000.

ACKNOWLEDGEMENTS

The authors wish to thank EU and GSRT for funding the projects within the framework of which the presented measurements and analyses were performed. Thanks are also expressed to the CRES engineering and technical stuff for their contribution to the experiments .

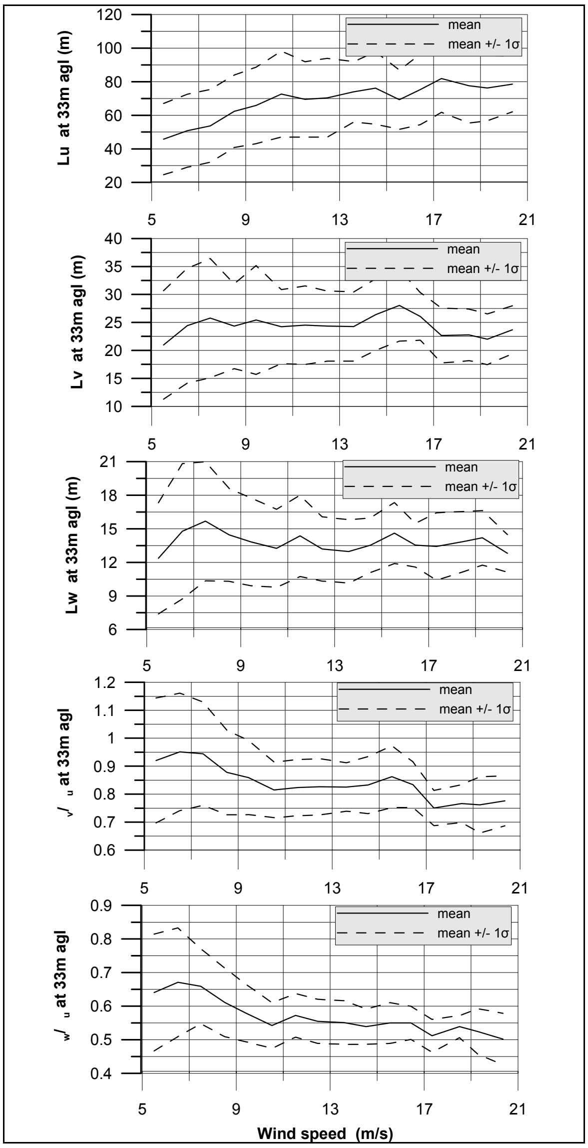

Figure 7. Length scale and turbulence ratios distributions at 33m agl.

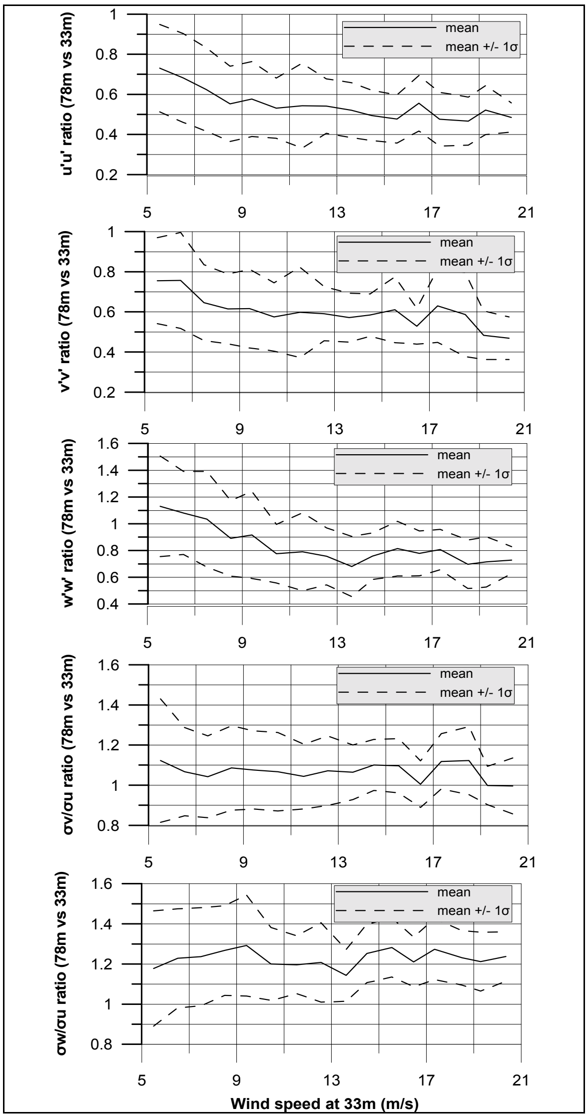

Figure 8. Diagonal Reynolds stresses, lateral and vertical turvulence ratios (78m vs 33m agl).

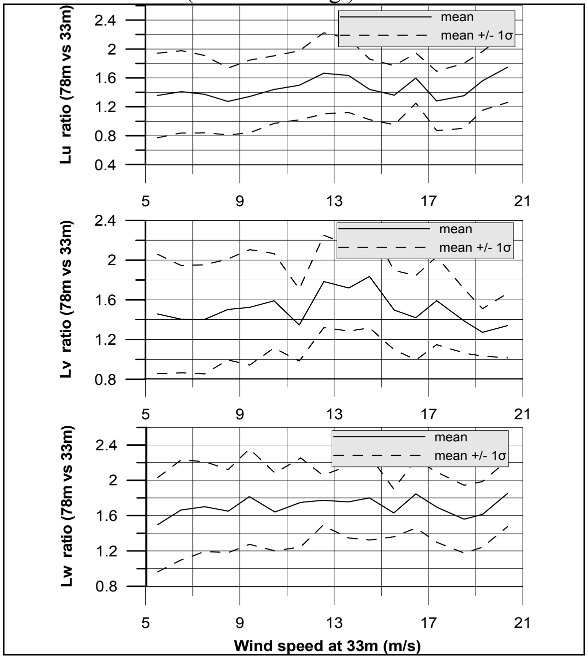

Figure 9. Length scale ratios (78m vs 33m agl).