TURBULENCE CHARACTERIZATION IN A COASTAL ZONE USING SONIC ANEMOMETRY

Bernardo Figueroa-Espinoza and Paulo Salles

LIPC, Instituto de Ingeniería.

Universidad Nacional Autónoma de México

Puerto de abrigo S/N, Sisal, Yucatán, México, 97355

bfigueroae@ii.unam.mx, psallesa@ii.unam.mx

ABSTRACT

Given that the shoreline and other complex terrain features preclude the use of Monin-Obukhov similarity to characterize turbulence, an experimental investigation was carried out in a Coastal Zone so the use of sonic anemometry to obtain turbulent variables is explored. In particular, it was observed that frequency domain spectra are similar to those described by the literature, so an attempt to estimate the dimensionless dissipation was carried out. With the use of an experimental correlation for the Obukhov Length in terms of local variables, the results for the dimensionless dissipation in a stably stratified atmosphere are remarkably similar to those reported in the literature for homogeneous terrain.

INTRODUCTION

The presence of terrain features that interact with atmospheric flows makes it difficult to parameterize turbulence in complex terrain. When a sudden change of roughness interacts with the main flow, an internal boundary layer (IBL) forms (Garrat, 1990; Sabelyev and Taylor, 2001). This IBL represents the region where the effect of the roughness change influences the flow, and it has been studied in the past by several authors. Above its influence (or IBL height) the characteristics of the wind are almost equal to those far upwind, and this IBL height increases with fetch according to the wind velocity, atmospheric stability and the ratio between the roughness length before and after the step change (Elliot, 1968; Miyake, 1965). The way this IBL affects turbulence has also been studied experimentally and numerically (Rao et al., 1974), using different turbulent parametrizations such as RANS or LES (Bou-Zeid et al., 2007). However, the effect an IBL has on frequency domain data as well as on the dissipation is still not well understood. An example of the calculation of the dissipation rate of turbulent kinetic energy can be found in Zhang (1999), where the dissipation is calculated as a function of the stability variable z/L (where L is the Obukhov Length), for different types of terrain, ranging from urban to grassland (see also Roth and Oke, 1993). In an attempt to shed some light on this matter, data coming from a meteorological mast near the coastline of the Gulf of Mexico in the state of Yucatán, México was analysed.

METHODOLOGY

A 50m meteorological mast was set up at 100m from the shoreline, equipped with five (Thies® CLIMA 38XX series) sonic anemometers at different heights (3, 6, 12.5, 25 and 50 m) from the ground level. Two of the anemometers were 3D (12.5 and 50 m) and the rest were 2D. The experiment, as well as the details of data processing are described more comprehensively in Figueroa-Espinoza et al. (2014) and Figueroa-Espinoza and Salles (2014b). The sampling rate was 10 Hz and the raw data was saved using a RF radio connected to a Data-Logger on one side, and to the network on the other. The data was selected using error detection routines, as well as visual inspection of the data and a stationariy criteria (Foken and Wichura, 1996). The turbulent variables were obtained from the velocity and virtual temperature fluctuations using the Eddy Covariance technique. Averaging was performed for a period of half an hour, according to an Ogive test (Oncley, 1995; Foken and Wichura, 1996). The data used in this study correspond to a period between August 2010 and August 2011.

RESULTS

To illustrate the effect of the IBL formed when the wind blows from the dominant direction, Figure 1 presents the (logarithmic) height above the terrain ln(z) as a function of the wind speed, normalized as $\kappa U/u_*$, where κ is the Von Karmán constant (here considered to be κ=0.4), U is the speed and u_* is the local friction velocity, obtained from the sonic anemometer. The figure on the left represents winds coming from land, while the figure to the right resulted from winds coming from the sea. Both figures correspond to neutrally stable atmosphere (z/Λ<0.01 on both 3D anemometers, and additionally U>4 m/s), where Λ is the Local Obukhov Length, defined as:

$$\Lambda = -T_v u_*^3/(g\kappa \overline{w'T'_v})$$

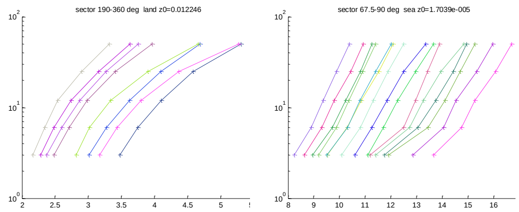

Figure 1: vertical speed profiles for winds coming from land (left) and winds coming from the sea (right).

Where T_v is the virtual temperature (approximated from the sonic Temperature), g is gravity and w is the vertical velocity component. The primes denote fluctuations around the mean values. It is clear that there is an IBL causing deviations from the straight lines one would expect to observe for neutrally stratified atmosphere. Note that winds coming from the sea present a small discontinuity in the slope of the profile around z=9 m, while wind velocity profiles coming from land present a discontinuity at about z=20 m; these heights must correspond approximately to the IBL height at the location of the mast.

Firstly, frequency domain information is presented in terms of the Power Spectral Density (PSD). Figure 2 shows some typical PSD plots for different seasons of the year.

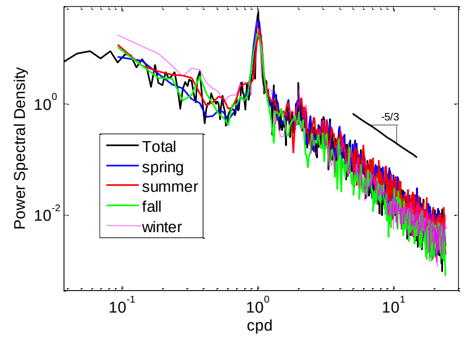

Figure 2: Power spectral density for different seasons of the year.

Note the peak at one cycle per day (cpd). A smaller peak is also detectable at two cpd (as a result of a breeze regime, stronger during the spring). The inertial subrange is clearly recognizable from the -5/3 slope at moderately high frequency (24 cpd).

Secondly, high frequency data (10 Hz) was processed as described before (Eddy Covariance) in order to estimate the dissipation, in virtue of the spectral density cast in terms of the nondimensional dissipation rate of turbulent kinetic energy $\phi_\varepsilon=\kappa z\varepsilon/u_*^3$ (Kaimal, 1972):

$$\frac{nS(n)}{u_*^2} = \frac{\alpha}{(2\pi\kappa)^{2/3}}\phi_\varepsilon^{2/3}f^{-2/3}$$

where α is a constant whose numerical value is close to α=0.5. Spectral densities were calculated for different atmospheric stability conditions, the inertial subrange was recognized from the 2/3 slope region at high frequency, and the dimensionless dissipation was estimated using a least squares best fit from the coefficient of the frequency $f^{2/3}$. The nondimensional dissipation values ϕ_ε were averaged and reported as a function of the Local Obukhov Length Λ. The relationship between Λ and the Obukhov Length L was previously studied for this case in Figueroa-Espinoza and Salles (2014b), so the results could be reported in terms of the stability variable z/L.

The main result is presented in Figure 3, where the dimensionless dissipation ϕ_ε (bin averaged) is shown as a function of z/L, for winds coming from land (black circles). The results from the Kansas experiment (Kaimal, 1972) are also shown for comparison (homogeneous terrain), as well as the results of Zhang (1988) corresponding to patchy suburban terrain (Fangshan in Beijing, China). The resemblance with the homogeneous results for stratified conditions is remarkable, however there are discrepancies for unstable atmosphere. This is probably because we were not able to establish a clear dependence between the Local Obukhov Length Λ and L due to large scattering of our data. Note that if the results were plotted as a function of the Local Obukhov Length (not shown here for brevity) they would resemble those of Zhang (smaller dissipation), showing that the relationship between these two variables is very important and should be further investigated.

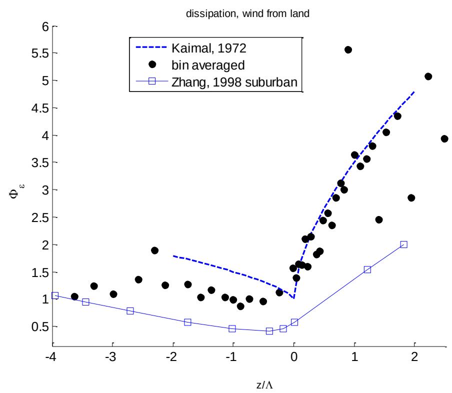

Figure 3: dimensionless dissipation as a function of z/L. Experiments are filled circles, dashed line from Kaimal (1972) and squares from Zhang, 1998.

CONCLUSIONS

The influence of mild terrain complexity on the spectral density is not too strong, so it is possible to use frequency domain data to obtain important turbulence characteristics such as the dissipation of turbulent kinetic energy, which may be used, for example, to develop parametrizations for numerical models of the atmosphere. In the case of complex terrain it is important to take into account the relationship between the Local Obukhov Length Λ (obtained with the anemometer data at height z) and L, otherwise the results may be misleading.

The authors respectfully acknowledge the support CONACYT, CFE, the Yucatán State Government through the projects FONSEC-CFE 89073 and FOMIX 106400, as well as the UNAM-**PAPIIT** Project grant number **IB100513**.

REFERENCES

Bou-Zeid E., Meneveau C. and Parlange M.B. (2007). Large-eddy simulation of neutral atmospheric boundary layer flow over heterogeneous surfaces: Blending height and effective surface roughness. *Water Resour. Res.*, 40-2, CiteID W02505.

Elliott W.P. (1968) The growth of the atmospheric internal boundary layer. *Trans. Amer. Geophys. Union*, 39, 1048-1054

Figueroa B., Salles P. (2014) Local Monin Obukhov similarity in Heterogeneous Terrain. *Atmos. Sci. Letters*, doi: 10.1002/asl2.503.

Figueroa B., Salles P. And Zavala J. “On the Wind Power Potential in the northwest of the Yucatan Peninsula in Mexico”. Atmosfera, 27-1,77-89, ISSN: 0187-6236, 2014.

Foken Th. and Wichura B. (1996) Tools for quality assessment of surface-based flux measurements. *Agr. Forest Meteorol*. 78, 83-105.

Garrat J.R. (1990). The internal Boundary Layer – A Review. B*ound.-Lay. Meteorol.*, 50, 171-203.

Kaimal J.C., Wyngaard J.C., Izumi Y. and Coté O.R. (1972). Spectral characteristics of sufrace-layer turbulence, *Quart. J. R. Met. Soc.*, 98, 563-589.

Miyake, M. (1965) Transformation of the Atmospheric Boundary Layer over Inhomogeneous Surfaces, *Sci. Rep, 5R-6*, Univ. of Washington, Seattle, U.S.A.

Oncley S.P., Fiehe C.A., Larue C., Businger J.A., Itsweire E.C. and Chang S.S. (1995): Surface-Layer Fluxes, Profiles, and Turbulence Measurements over Uniform Terrain under Near-Neutral Conditions, *J. Atmos. Sci*, 53-7, 1029-1044.

Rao K.S., Wyngaard J.C., and Coté, 0.R.: 1974, The Structure of Two-Dimensional Internal Boundary Layer over a Sudden Change of Surface Roughness, J. *Atmos. Sci.* 31, 738-746.

Roth M., and Oke T.R. (1993). Turbulent transfer relationships over an urban surface: I. Spectral characteristics. *Q. J. R. Meteorol. Soc*. 119, 1071–1104.

Savelyev S.A. and Taylor P.A. (2001). Notes on an internal boundary-layer height formula. *Bound.-Layer Meteorol*. 101, 293-301.

Zhang H. and Park S. (1999). Dissipation rates of turbulent kinetic energy and temperature and humidity variances over different surfaces. *Atmos. Research*, 50, 37-51.