TURBULENCE STRUCTURE AND SIMILARITY THEORY OVER COMPLEX TERRAIN IN STABLE CONDITIONS

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1. Introduction

The structure of turbulence over flat, homogeneous surfaces and various atmospheric conditions is sufficiently understood nowadays. Measurements of turbulence structure of these areas have led to similarity theories.

However, in recent years, the efforts to describe the turbulent boundary layer have focused on more complex surfaces. Another major concern of boundary layers studies is the very stable regime .

Areas of complex terrain may not allow a local equilibrium to be formed except very close to the surface. Based on theory, Jackson and Hunt (1975) have suggested the existence of a two-layer turbulence structure over complex terrain. In the so-called inner layer (near the surface) turbulence is expected to be in equilibrium with the current boundary conditions, hence the turbulence structure can be predicted on the basis of surface-layer laws. In the overlying outer layer, turbulence is expected to be modified by the so-called rapid distortion effect.

For stable conditions the description of the structure of the boundary layer in terms of similarity functions vary substantially between studies. While, for instance, vertical turbulent fluxes vanish using the bulk formulas with existing stability functions (Beljaars and Holstlag, 1991) others fields observations (Webb, 1970; Mahrt et al., 1979; Dias et al., 1995), laboratory studies (Yamada, 1979; Lienhard and Van Atta, 1990) and numerical simulations (Holt el al., 1992; Kaltenbach et al., 1994) shows that some turbulence intensity persists even in very stable conditions. Also many authors (Carson and Richards, 1978; Nieuwstadt, 1984; Högström, 1988; Holtslag and De Bruin, 1988) suggest that the f stability functions deviate from Businger-Dyer formula as the stability increases.

Since the results from several studies are not always in agreement, additional data in complex terrain and stable conditions are still essential in helping the understanding of the structure of the turbulence in these conditions. This is purpose of this paper.

2. Experimental Details

Data were taken at the Dona Francisca Hidroelctric Power Plant in the south of Brazil, from August , to September 1999. In this part of the Jacui River Valley, the ridges are typically 350 m high. The region is mostly forested except for small farms in the valley. The tower is on the base of a ridge which has an average elevation of about 300 m above the floor of the Valley. The monitoring turbulent system at the site consisted of a three-component Campbell sonic anemometer and Krypton hygrometer located a 10 m level of the tower. Slow response sensors as Vaisala temperature and humidy probe, R. M. Young propelors anemometers, Vaisala pressure sensor and net radiometer were also used.

Data from four nights are used in this study. All the data were screened for continuity, and the choosed nights have more than 99% of recovery data. Missing data were filled in by assigning to these points the most recent valid value.

3. Micrometeorological Parameters

In this paper the friction velocity (u_*), the turbulent kinetic energy (e) the vertical heat flux ($\overline{w'q'}$) and, the standard deviations of the temperature and turbulent vertical velocity were estimated with the method presented by Howell and Sun (1999). In this method the computed parameters are based on the relationship between the scale dependence on the parameter and associated random errors from time series of the data. For a data record consisting of 2^M data points, there are 2^{M-m} nonoverlapping windows for statistical estimates, which are associated with the cut-off scale of 2^m points (Howell and Mahrt, 1997). In this study u_*, e, $\overline{w'q'}$, s_q and s_w were calculated at six cut-off scale from 2^{10} ($\cong 100\,\mathrm{sec}$) to 2^{15} data points ($\cong 25\,\mathrm{min}$) for each night . Some results are presented in Figures 2 and 3 for wind velocity lower than $1\,ms^{-1}$ and greather than $3\,ms^{-1}$.

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4. Results and Discussion

For strong winds ($\overline{U} > 3\,m/s$) the vertical component s_w / u_* (Figure 1a) shows a clear dependence with z/L for the weakly stable regime, which is in agreement with observations over flat (Smedman, 1988), as well as over complex areas (Gallagher et al., 1988). The minimum occurs around the neutral limit. On the other hand, for very stable conditions the scaled variance increases with increasing z/L. According to Mahrt (1999) this could be associated with inadvertent capture of non-turbulent motions in the calculations of the standard deviation. For the same condition, i.e. $\overline{U} > 3\,m/s$, the turbulent kinetic energy decreases with increasing stability, reaching a constant value for $z/L > 0.5$ (Figure 1b). The persistency of turbulence for strong stability could also be associated with non-turbulent motions captured by the instruments. The vertical heat flux (Figure 1c) is approximately independent of the stability parameter. This could be due to self-correlation between predicted variables and predictor functions.

A large dispersion in the values of s_w / u_*, e / s_w^2 and $H / s_w s_q$ is observed when $\overline{U} < 1\,m/s$ both for weakly and very stable conditions (Figure 2). Large dispersion estimations in some micrometeorological parameters are not unusual, and has been observed in many experimental studies over complex and flat terrain (Bradley, 1980; Sacre and Flori, 1989). However, in this case, when the mechanical input for the turbulence is weak, there is no indication that the calculated variables present dependence with the Monin-Obukhov Stability parameter.

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References

Beljaars, A.C.M. and Holstlag, A.A.M. 1991: Flux Parameterization over Land Surfaces for Atmpospheric Models, *J. Appl. Meteorol*., **30**, 327-341.

Bradley, E.F. 1980: An Experimental Study of the Profiles of the Wind Speed, Shearing Stress and Turbulence at the Crest of a Large Hill, *Quart. J. Roy. Meteorol. Soc.*, **106**, 101-124.

Carson, D.J. and Richards, P.J. 1978: Modelling Surface Turbulent Fluxes in Stable Conditions, *Boundary-Layer Meteorol*., **14**, 67-81.

Dias, N.L., Brutsaert, W., and Wesely, M.L. 1995: Z-less Stratification under Stable Conditions, *Boundary-Layer Meteorol*., **75**, 175-187.

Gallagher et al., 1988

Högström, U. 1988: Non-Dimensional Wind and Temperature Profiles in the Atmospheric Surface Layer: A Re-Evaluation, *Boundary-Layer Meteorol*., **42**, 5-78.

Holt, S.E., Koseff, J.R., and Ferzinger,J.H. 1992: A Numerical Study of the Evolution and Structure of Homogeneous Stably Stratified Sheared Turbulence, *J. Fluid Mech*., **237**, 499-539.

Holtslag, A.A.M. and De Bruin, H.A.R. 1988: Applied Modeling of the Nightime Surface Energy Balance over Land, *J. Appl. Meteorol*., **27**, 689-704.

Howell, J.F. and Mahrt, L. 1997: Multiresolution Flux Decomposition, *Boundary-Layer Meteorol*., **83**, 117-137.

Howell, J.F. and Sun, J. 1999: Surface Layer Fluxes in Stable Conditions, *Boundary-Layer Meteorol*., **90**, 495-520.

Jackson, P.S. and Hunt, J.C.R. 1975: Turbulent Wind Flow Over a Low Hill, *Quart. J. Roy. Meteorol. Soc.*, **101**, 929-955.

Kaltenbach, H.-J., Gerz, T., and Schumann, U. 1994: Large-Eddy Simulation of Homogeneous Turbulence and Diffusion in Stably Stratified Shear Flow, *J. Fluid Mech*., **280**, 1-40.

Lienhard, J.H. and Van Atta, C.W. 1990: The Decay of Turbulence in Thermally Stratified Flow, *J. Fluid Mech*., **210**, 57-112.

Mahrt, L., Heald, R.C., Lenschow, D.H., and Stankov, B.B. 1979: An Observational Study of the Structure of the Nocturnal Boundary Layer, *Boundary-Layer Meteorol*., **17**, 247-264.

Mahrt, L. 1999: Stratified Atmospheric Boundary Layer, *Boundary-Layer Meteorol*., **90**, 375-396.

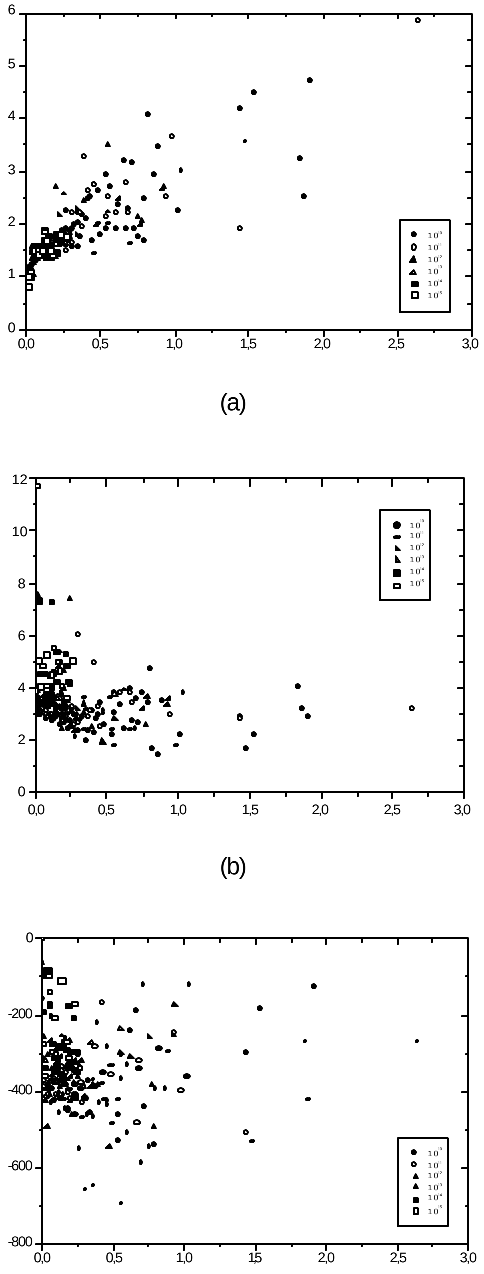
Nieuwstadt, F.T.M. 1984: The Turbulent Structure of the Stable, Nocturnal Boundary Layer, *J. Atmos. Sci*., **41**, 2202-2216.

Sacre, C. and Flori, J.P. 1989: Turbulence Characteristics in Complex Terrain for Wind Turbines Setting Up, *Proc. European Wind Energy Conference,* Glasgow, U.K., (Peter Peregrinus, London), pp 523-526.

Smedman, A. 1988: Observations of a Multi-level Turbulence Structure in a Very Stable Atmospheric Boundary Layer, *Boundary-Layer Meteorol*., **44**, 231-253.

Webb, E.K., 1970: Profile Relationships: The Log-Linear Range, and Extension to Strong Stability, *Quart. J. Roy. Meteorol. Soc*., **96**, 67-90.

Yamada, T. 1979: PBL Similarity Profiles Determined from a Level-2 Turbulence Closure Model, *Boundary-Layer Meteorol*., **17**, 333-351.

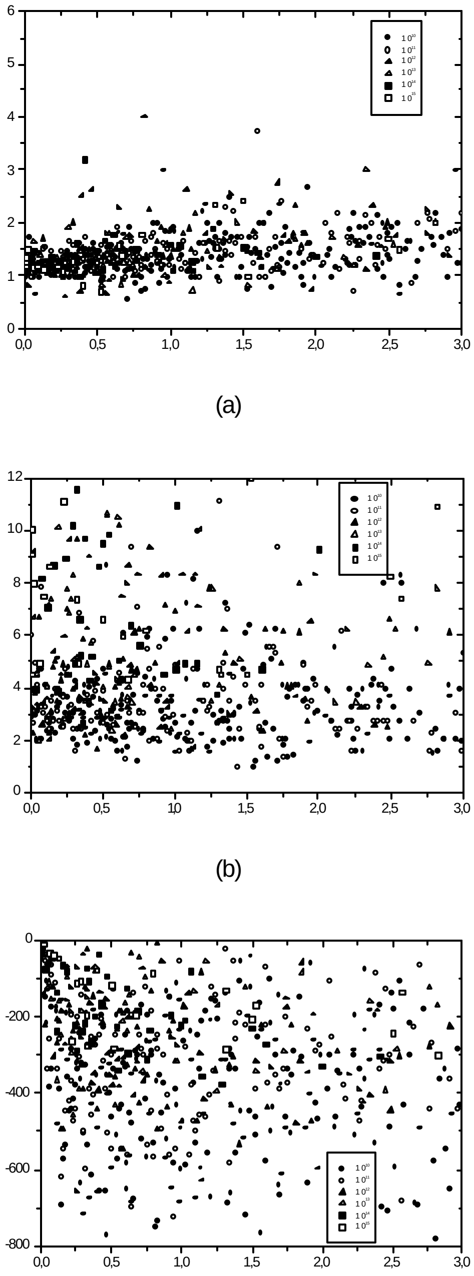


(a)

(b)

(c)

Figure 1: s_w/u_* (on the top), e/s_w^2 (on the middle) and $H/s_w s_q$ (on the bottom) as a function of z/L based on the four nights of data and for wind velocity greather than 3m/s. The corresponding cut-off time scale are shown in the box.



(a)

(b)

(c)

Figure 2: Same as Figure 1 but for wind velocity lower than 1m/s. The corresponding cut-off time scale are shown in the box.