STRUCTURAL PARAMETERS IN THE CONVECTIVE ATMOSPHERIC BOUNDARY LAYER

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1. Introduction

The complexity of the turbulent flow in the atmospheric boundary layer is most often described in terms of various statistical moments of basic meteorological parameters. An understanding of the spatial and temporal distribution of these moments, their appropriate theoretical description, and accurate prediction, is therefore a crucial problem for both modelers and experimenters. During the last decades a framework of the Monin-Obukhov scaling, together with an extensive experimental effort, has led to the accumulation of substantial knowledge of various statistical moments in the atmospheric surface layer. An understanding of the boundary layer above complex terrain (i. e., forests) has been improving more slowly due to measurement difficulties and a lack of simple theoretical framework analogous to the Monin-Obukhov similarity theory. So, these studies are necessary for solving important problems affecting society such as global climate change and the buildup of pollutants.

To date there are no available atmospheric data that allow a determination of the variation of structure parameters as a result of non-homogeneous boundary conditions. It seems worthwhile, however, to establish the stability dependence of these parameters from existing data in a surface layer over a complex terrain like the Amazon forest.

2. Basic Considerations

Let us now consider the moments of the turbulent fluctuations in unstably stratified boundary layers and begin with second-order moments. There turbulence structure parameters which have been defined and measured in turbulent shear flows are

$$a_i = - \overline{uw} \, / \, \overline{u_i^2} \tag{1}$$

where i = 1, 2, and 3 (i. e., for the fluctuations of velocity components u, v, and w in the 0x-, 0y- and 0z- directions, respectively), $\overline{u_i^2}$ is the turbulence kinetic energy $\overline{u}^2 + \overline{v}^2 + \overline{w}^2$,

$$a_\theta = \overline{w\theta} \, / \, [\sigma_\theta (\overline{-uw})^{1/2}] \tag{2}$$

$$a_q = \overline{wq} \,/\, [\,\sigma_q(\overline{-uw})^{1/2}] \qquad (3)$$

here $\overline{w\theta}$ and $\overline{wq}$ are the sensible and latent heat flux, respectively; $a_\theta(=(\overline{\theta^2})^{1/2})$ and $a_q(=(\overline{q^2})^{1/2})$ the standard deviations of temperature and humidity fluctuations, respectively. In the atmospheric surface layer, the above definitions can be rewritten, assuming variations with height of the fluxes are negligible, as

$$a_i = u_*^2 \,/\, \overline{u_i}^2 \quad ; \quad a_\theta = \theta_* \,/\, \sigma_\theta \quad ; \; a_q = q_* \,/\, \sigma_q \qquad (4a,b,c)$$

where u_*, θ_* and q_* are the scaling velocity $(\equiv(\overline{-uw})^{1/2})$, scaling temperature $(\equiv \overline{w\theta} / u_*)$ and scaling humidity $(\equiv\overline{wq} / u_*)$, respectively. Monin and Obukhov (1954) used neither dynamic equations nor semi-empirical hypothesis but based all their conclusions only on general similarity and dimensional arguments. However, in terms of Monin-Obukhov similarity, a_i, a_θ and a_q are expected to be uniquely determined by the stability parameter $\zeta(= -(z-d)/L$, $L= -u_*^3/k(\overline{w\theta})\beta$ the Monin-Obukhov length, β is the buoyancy parameter $g/\overline{T}$, g the acceleration due to gravity, $\overline{T}$ the mean temperature, $k=0.4$ the von Karman constant, z the height above surface and d the zero-plane displacement), such that

$$a_i = f_i(\zeta); \qquad a_\theta = f_\theta(\zeta); \qquad a_q = f_q(\zeta). \qquad (5a,b,c)$$

In the local free convection conditions, the expected behavior of these structure parameters is

$$a_i \propto (\zeta)^{-2/3} \; ; \qquad a_\theta, a_q \propto (\zeta)^{1/3} \qquad (6a,b,c)$$

An experimental verification of the behavior (in particular the stability dependence) of a_i, a_θ and a_q over the complex terrain in the atmospheric surface layer seems important, particularly with regard to the formulation of calculation methods for atmospheric shear flows and models (Brashaw et al., 1967; Antonia and Luxton, 1971; Wyngaard, 1973; Antonia et al., 1977; Viswanadham, 1982; Kadar and Yaglom, 1990).

3. Experimental Site and Measurements

The place selected for the experiment is in the tropical evergreen forest of the Amazon basin, Brazil. The measurements were made using a 45 m scaffolding tower at the Ducke Reserve Forest (DRF) site (2°57' S; 59°57' W), 26 km from Torquato Highway, Manaus, Amazonas. The altitude of the DRF site is 84 m above the mean sea level. The DRF belongs to the Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, AM, Brazil. The reader is referred to the paper by Viswanadham et al. (1990) for information on the DRF, the vegetation cover, the fetch at site, determination of the roughness length z_o (= 2.2 m), the zero plane displacement d (= 31 m) and other information on the experimental setup and measurement of Hydra data including various parameters that are not repeated here.

3. Results

The brief report presents the results of the high frequency velocity fluctuation measurements over the Amazon forest canopy. These measurements are very important to understand the dynamics of the Amazon boundary layer where the turbulent transfer activity is very vigorous. Therefore, to clarify the behavior of velocity, temperature, and humidity statistics, it was decided to analyse the Hydra measurements of second-moment components for three days in August 1984. Variations of a_1, a_2, a_3, a_i, a_θ and a_q with $-\zeta$ for the Amazon one-hour averages of Hydra data are given in Figs. 1 and 2. The horizontal velocity fluctuations appear to attain fairly constant values at moderate instabilities easily achieved very near the surface and then retain these values in the lower mixed layer (Fig. 1). The vertical component behaves quite differently, as would be expected on physical grounds. The major effect of additional buoyancy energy would be expected to appear in the vertical velocity field. Inspection of Eq. (6a) shows this feature rather nicely; eddies are elongated along the wind shear above the canopy surface in unstable conditions (i.e., $u^2 > v^2$), but quickly become more circular in a horizontal cross section as height increases (i.e. $v^2 \rightarrow u^2$ as ζ increases).

For $-\zeta > 0.3$, the free convection relation for a_θ and a_q, Eqs. (6b,c), appears to be reasonably supported by the data. The -2/3 behavior for a_1, a_2, a_3 and a_i Eq. (6a), is not as clear, although $a(-\zeta)^{1/3}$ behavior appeared to be convincingly followed by the data for σ_w/u_*. All the corresponding regression relations are given below Figs. 1 and 2. Limited space prevents further elaboration results.

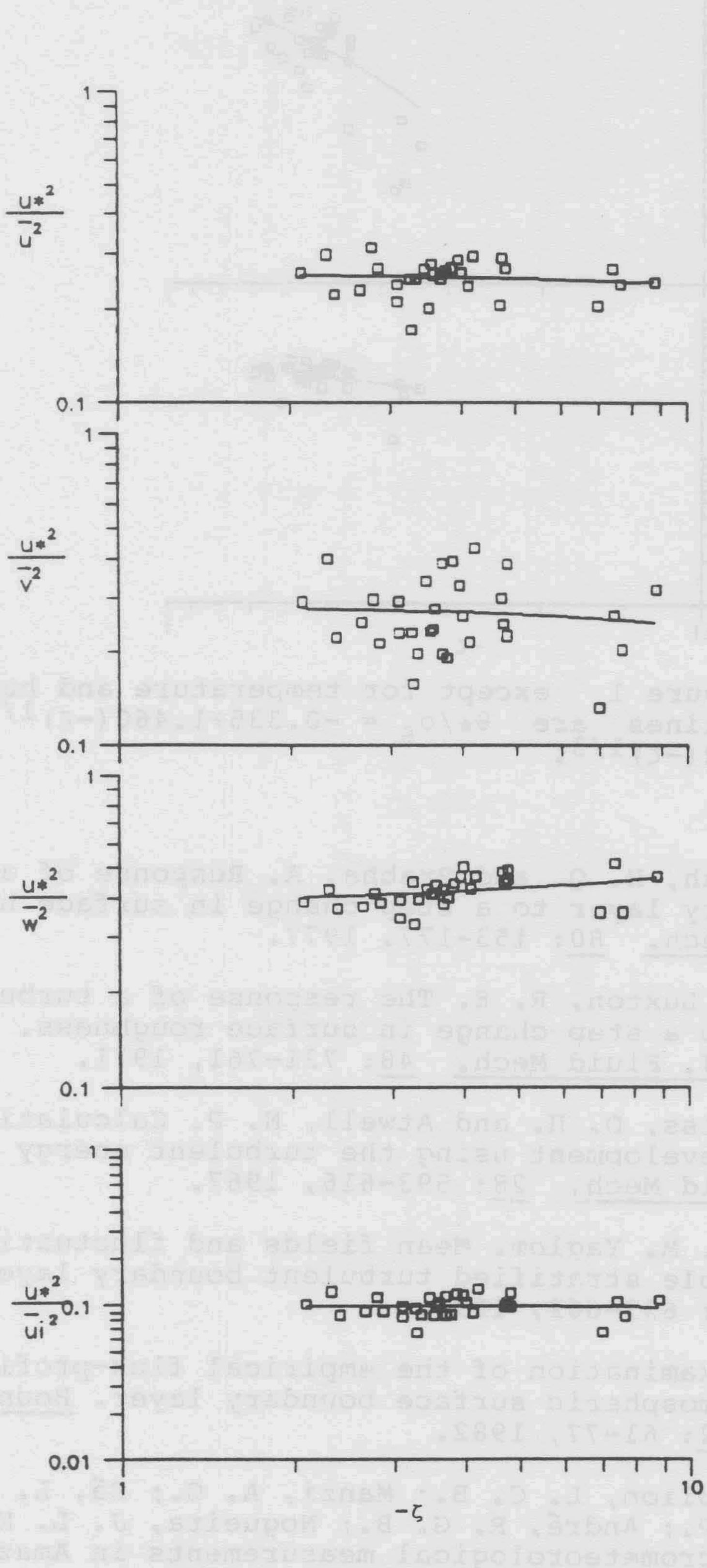

Fig. 1. Dependence of individual turbulence components on ζ for the Amazon forest data at 48.7 m. The regression lines are $u_*^2/\overline{u}^2 = 0.261-0.0018(-\zeta)^{-2/3}$; $u_*^2/\overline{v}^2 = 0.286-0.0043(-\zeta)^{-2/3}$; $u_*^2/\overline{w}^2 = 0.384+0.0093(-\zeta)^{-2/3}$ and $u_*^2/\overline{u}_i^2 = 0.1-0.0005(-\zeta)^{-2/3}$.

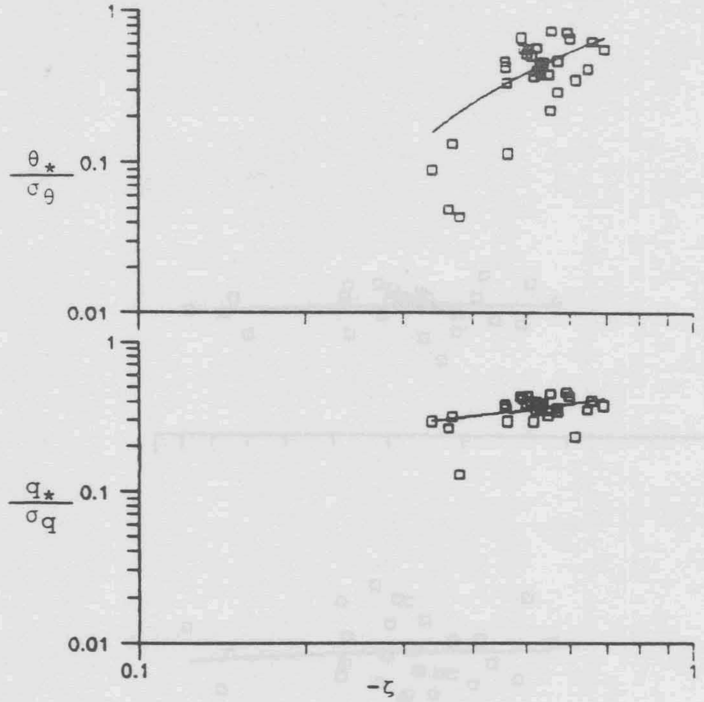

Fig. 2. As in figure 1 except for temperature and humidity. The regression lines are $\theta_*/\sigma_\theta = -0.335+1.460(-\zeta)^{1/3}$ and $q_*/\sigma_q = 0.178+0.352(-\zeta)^{1/3}$.

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