Physica A 392 (2013) 1510–1521

Contents lists available at SciVerse ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Characterizing the relative role of low-frequency and turbulent processes in the nocturnal boundary layer through the analysis of two-point correlations of the wind components

Claudio A. Teichrieb [a,*], Otávio C. Acevedo [a], Gervásio A. Degrazia [a], Osvaldo L.L. Moraes [a], Débora R. Roberti [a], Hans R. Zimermann [a], Daniel M. Santos [a], Rita C.M. Alves [b]

[a] Universidade Federal de Santa Maria, Santa Maria, RS, Brazil
[b] Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

ARTICLE INFO

Article history:
Received 7 November 2012
Available online 29 November 2012

Keywords:
Multiresolution decomposition
Nocturnal boundary layer
Two-point correlations

ABSTRACT

The study presents an analysis of two-point correlations between time series of nocturnal atmospheric wind, obtained from two micrometeorological towers, 45 m horizontally apart, each equipped with two sonic anemometers, 2.5 m vertically apart. It focuses on the scale dependence of the two-point correlations obtained from sensors vertically and horizontally separated. In particular, the role of low-frequency non-turbulent processes in the correlations is assessed, and compared to that of the turbulent scales of motion. The vertical correlations of the streamwise and vertical wind components show little dependence on the turbulence intensity, but those of the spanwise component decrease appreciably as it gets more turbulent. Multiresolution decomposition shows that the two-point correlations become increasingly dominated by low-frequency scales as it gets less turbulent, and that such large-scale processes are largely reduced in fully turbulent conditions. It is also shown that the vertical correlations of the spanwise wind component is negative for very small time scales. Horizontal two-point correlations obtained at the 45 m separation distance between the towers are almost entirely dominated by low-frequency motions, regardless of the turbulence intensity, but the magnitude of such correlations decreases with increasing turbulence intensity for any wind components. A comparison between the horizontal two-point correlations and autocorrelations taken with a time lag given by the ratio of the horizontal separation to the mean wind component in the direction that connects the two towers leads to the conclusion that the statistical properties of turbulence are often preserved over the horizontal distance, despite the lack of turbulence correlations for that separation.

1. Introduction

The presence of spatial correlations between remote fluid elements in turbulent motion is one of the most important characteristics that set this process apart from its molecular counterpart. Such correlations are ultimately responsible for placing turbulent diffusion as the dominant form of transport of both scalar and vectorial species in geophysical flows.

* Correspondence to: Departamento de Física, Universidade Federal de Santa Maria, Santa Maria, RS, 97105-900, Brazil. Tel.: +55 55 33012033; fax: +55 55 32208032.
E-mail address: teichrieb@gmail.com (C.A. Teichrieb).

0378-4371/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.physa.2012.11.009

As a consequence, the determination of the typical length scales that characterize such spatial correlations is essential for building physically realistic parameterizations of exchange coefficients for heat, humidity, momentum and contaminant concentrations.

The analysis of two-point correlations between wind velocity components observed at different locations has been used largely to provide information on the three-dimensional structure of the turbulent flow. Such a procedure has been applied to observational data obtained from wind tunnels using hot wire anemometry [1,2] or particle image velocimetry (PIV, [2,3]) and to numerical datasets, originated from both direct numerical simulations (DNS, [4]) and large eddy simulations (LES, [5,6]). Recently, Hutchins et al. [7] performed a detailed analysis of two-point correlations observed at the atmospheric boundary layer, showing that their results compared well with the existent knowledge originated from the laboratory. Prior observational studies of two-point correlations in the atmospheric boundary layer emphasized the spatial coherence function and how it decays with the spatial separation between the two points [8–10].

The above-mentioned studies focus on the turbulent structure of the flow. For this reason, they typically filter out any larger-scale forcing on the wind components. This is particularly important when atmospheric boundary layer data are used. With that motivation, Hutchins et al. [7] filtered out large-scale processes that appeared as the average over a horizontal array of sensors and, furthermore, considered only data obtained at near-neutral atmospheric stability. The importance of low-frequency non-turbulent processes at the atmospheric boundary layer has been increasingly recognized in recent years [11]. In fact, such processes are known to affect the total budget of scalars in a way that their consideration improves the budget closure [12,13]. In particular, low-frequency processes have an important role in the very stable nocturnal boundary layer.

In the present study, nocturnal atmospheric boundary layer data are used to provide information on the horizontal and vertical spatial correlations of the three wind components. The analysis focuses on specific topics, not fully addressed by previous observational studies of two-point correlations in the atmospheric boundary layer. The first is the correlation dependence on the turbulence intensity. The second (and most relevant) aspect analyzed regards the time scale dependence of the two-point correlations. This is done using multiresolution decomposition, a technique that allows identifying the contribution of events happening at different temporal scales to a given signal. Such an analysis allows identifying how different flow structures contribute to the observed two-point correlations. This is particularly relevant at the nocturnal atmospheric boundary layer because many different processes, such as turbulence intermittency [14,15], meandering [16–18], gravity waves [19,20] and others may coexist, originating relevant low-frequency fluxes, sometimes also regarded as mesoscale or submeso fluxes [11,21].

The paper is structured as follows. In Section 2, the data are described, and the analysis techniques are presented. Section 3 is devoted to the analysis of the two-point correlations in the vertical direction, and in Section 4 those obtained at the horizontal direction are described. In each case, the analysis starts with the correlation dependence on the turbulence intensity and then their time scale decomposition is performed and discussed. In Section 4, autocorrelations are also analyzed and compared to the two-point horizontal correlations using Taylor's hypothesis.

2. Observations and methods

2.1. Data

Two micrometeorological towers have been installed at a corn plantation field, in Cruz Alta, southern Brazil (28°36′S; 53°40′W), as part of a project that aimed at comparing the carbon fluxes from the plantations. The towers were horizontally separated by 45 m in the horizontal direction, and at each of them observations were taken at 2.5 and 5 m heights from the surface (Fig. 1), giving four observational points, where the three wind components were sampled at 10 Hz by a Campbell CSAT3 sonic anemometer (Campbell Scientific, Inc.). In total, 94 days of observations were taken, from 2 December 2010 to 5 March 2011. The nocturnal period used in the present analysis was considered as starting at 2100 LST and ending at 0500 LST, chosen to avoid the evening and morning transition periods. A data quality analysis was performed. Nights were discarded for different reasons, such as rain, power failure, or others that caused inconsistent data. If some inconsistency occurred during a portion of a given night, that night was discarded entirely. The results described in the paper refer to the 73 nights that passed the quality control. The four sonic anemometers used were intercompared before and after the experiment, and no bias or offset was found.

2.2. Methodology

The scale chosen to classify the turbulence intensity in this study is σ_w, the standard deviation of the vertical wind perturbations. The reason is that σ_w is a pure turbulent quantity, being almost unaffected by large-scale meteorological processes. Other quantities, such as the friction velocity or the turbulent kinetic energy, depend more largely on low-frequency phenomena, and it is possible they do not reflect purely the turbulence intensity [22]. Three specific nights were chosen as case studies, each with a different turbulence intensity (Fig. 2). The night starting at 24 January 2011, with very low turbulence intensity ($\sigma_w = 0.12$ m s^{-1}) will be regarded throughout the study as a "calm night", while 14 December 2010 ($\sigma_w = 0.31$ m s^{-1}) is called an "intermediate night" and 29 December 2010 ($\sigma_w = 0.69$ m s^{-1}) is a "turbulent night".