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CONTRIBUTION OF COHERENT STRUCTURES TO SENSIBLE HEAT TURBULENT FLUXES DURING MAY 1995, IN CANDIOTA, RS, BRAZIL

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Abstract. Coherent structures may account for from 40 to 50% of the turbulent transports of latent and sensible heat in the Surface Layer. Those structures are characterized, in the convective period, by a slow increase of temperature, followed by a sudden drop. The present study intends to estimate the coherent structure (CS) contribution to sensible heat turbulent fluxes, applying intermittent function to detect them and quadrant analysis to evaluate the fluxes. The data was sampled at 1 Hz, in May 23rd 1995; during about an hour and thirty five minutes, in Candiota. About a hundred CS were analyzed, with an average of 17 CS every 15 minutes, a duration of 18.3±0.8 s, an intensity of 0.106 ºC, and an intermittence factor, which represents the part of the series due to the CS, of 37% . The quadrant analysis indicated that CS were responsible for up to 75% of the fluxes due to ejection (positive temperature and vertical velocity), but one case was identify with a larger contribution due to the sweep (both variables negative), which are a small part of the CS in each series. The quadrant analysis produced interesting results that must be pursued by exploring a larger data set.

Keywords. *Coherent structures, quadrant analysis, intermittent function, turbulent fluxes.*

1.Introduction

Large-scale motions that maintain coherence for at least sometime in the turbulent flow play an important role in the mechanics turbulent boundary layers (Boppe et al., 1999). Among those, there are coherent structures characterized, in the convective period, by a slow increase in temperature or humidity fluctuations followed by a sudden drop (Antonia et al., 1979), with a duration of about 30 s and length of about 100 m. They have been observed in atmospheric turbulence under several surface conditions and stabilities as well as in laboratory. Boppe et al. (1999) present a review of the spatial structure of quasi-coherent motions in the marine atmospheric surface layer. They identified that those coherent structures may be associated to vortical arches, as suggested by Robinson (1991). The coherent structure that will be the object of the present study is defined as the region of the temporal series which begins at the slow rise and ends at the sudden drop region. This definition is adequate to the application of the intermittent function as a conditional sampling technique (Krusche and Oliveira, 2004).

Nevertheless, due to their large range of duration and occurrence, along with their three-dimensional features, there is much to be unveiling about the coherent structures, specially their contribution to turbulent fluxes. This has been a central issue in the study atmospheric turbulence since Gao et al. (1989) proposed that these phenomena might be responsible for up to 75% of the turbulent fluxes in the Surface Layer.

Recently, several authors showed that was a particular case. For instance, Krusche and Machado (2000) determined contributions to the latent and sensible heat turbulent fluxes from 42 to 61%, while Lu and Fitzjarrald (1994) reported that coherent structures were responsible for about 40% of the turbulent sensible heat and momentum fluxes.

Actually, before estimations of turbulent flux contributions can be made, first the coherent structures must be detected by an objective technique. Conditional sampling techniques detect specific events in a temporal series, applying a minimum duration, which is a typical temporal scale, and some criteria that depends upon a limiar, which is related to a typical amplitude scale (Greenhut and Khalsa, 1982). In the pursue of solving the problem of selecting a technique, Krusche and Oliveira (2004) have recently demonstrated that the intermittent function, with an adaptation to use an objective limiar, is an effective conditional sampling technique to detect coherent structures in the atmospheric surface layer, along with the wavelet transform, following criteria given by Hagelberg and Gamage (1994).

In order to estimate the contribution of the coherent structures to the total turbulent flux, the methodology proposed by Katul et al. (1997) for quadrant analysis was then applied. They propose to split the fluxes in four quadrants, according to the value of the vertical velocity and temperature fluctuations. The convective period is characterized by large contributions to turbulent fluxes in the first quadrant (temperature and vertical velocity fluctuations are positive) and the third quadrant (temperature and vertical velocity fluctuations are negative), while the duration, or "residence" time in each quadrant, is larger in the third quadrant. Since the coherent structures are associated to a slow raising movement, probably their larger contribution would be in the first quadrant.

Therefore, this research aims to investigate the contributions of the coherent structures to the fluxes in each quadrant, in order to improve the estimate of their contribution to the total turbulent fluxes.

The measurements obtained during the Candiota experiments were available to perform the analysis outlined above. The dataset from the experiment that took place in May 1995 was selected. The analysis for May 23rd was accomplished and the results will be present in the third sections. The next section, the second one describes the data and the analysis procedure. In the forth section, the conclusions are displayed.

2. Methodology

2.1 Data

The Candiota project was composed of several meteorological experiments performed in the region of a thermoelectric power plant, located at 31°28'S and 53°40'W, in Candiota, RS, to establish the pollutant dispersion in that region. The data set was composed by temperature, and vertical, longitudinal, and transversal velocity fluctuations measured in May 23rd 1995. The wind was from northeast, the side forward that the sensors were fixed. The topography of the region is quite homogenous, especially in the northeast. Moreover, Machado and Krusche (2000) demonstrate that the intensity of the CS is larger, in Candiota, when the wind blows from that direction. The final data sets have seven files, containing about an hour and thirty-five minutes of measurements sampled at 1 Hz.

2.2 Intermittent Function

The intermittent function $I_a(t)$ of a temporal series a(t) is defined as (Hedley and Keffer, 1974):

$$I_a(t)=\begin{cases} 1, \text{ when } a(t)>\kappa_I \text{ during } \tau \\ \\ 0, \text{ otherwise} \end{cases} \tag{1}$$

where τ is the minimum event duration and κ_I is the limiar, which was chosen to be proportional to the standard deviation σ_a of the series. The limiar and, therefore, the proportionality constant, is chosen as the one for which $I_a(t)$ yields the maximum number of events. Although there is no guarantee that the maximum number of events represents the actual number of events, this is a reasonable objective criterion for selecting the threshold level. The minimum duration was kept constant and equal to 10 seconds.

2.3 Quadrant Analysis

This technique distributes the vertical flux in four sectors, according to the vertical movement and the sign of the other turbulent variable, which may be the horizontal velocity or a scalar such as temperature, humidity, or gas concentration (Gao et al., 1989). In the convective period, an ejection happens when an updraft carries warm air, that is, both the vertical velocity and the temperature fluctuations are positive, which defines the first sector. A sweep, during unstable conditions, is a downdraft transporting cold air, when both the vertical velocity and the temperature fluctuations are negative, and it settles the third sector. The second and the fourth sectors represent interactions. Figure (1) presents those definitions.

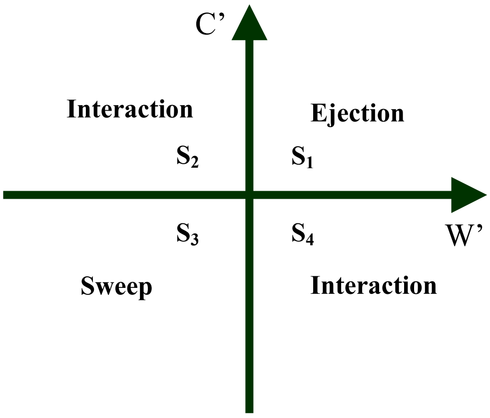

Figure 1 Quadrant analysis scheme is presented for convective periods, showing ejection, sweep, and interaction sectors, along with S_i, i=1,2,3,4, which represents the stress fractions. W' is the vertical velocity fluctuation and C' is the scalar fluctuation , which, in this case, is the temperature.

The stress fraction S_i for quadrant *i* is the flux contribution from that quadrant to the total flux (Katul et al.,1997). That can be expressed as:

$$S_i=\frac{\langle\langle wc\rangle\rangle_i}{wc} \tag{2}$$

where

$$\langle\langle wc \rangle\rangle_i = \frac{1}{T_p}\int_0^{T_p} w(t)c(t)I_i dt \tag{3}$$

and where w(t) is the vertical velocity turbulent component, c(t) is the scalar turbulent component, wc is the vertical turbulent flux due to scalar c, T_p is the sampling period, $\langle\langle\ \rangle\rangle$ are conditional averages and I_i is the indicator function defined by:

$$I_i = \begin{cases} 1, \text{ if coordinates (w,c) are within quadrant i, i=1,2,3,4} \\ 0, \text{ otherwise} \end{cases} \tag{4}$$

with $S_1+S_2+S_3+S_4=1$.

The total duration of events in quadrant i or time fraction of measurement events in quadrant i is also defined by Katul et al. (1997) as:

$$D_i = \frac{1}{T_p}\int_0^{T_p} I_i(t)\, dt \tag{5}$$

where D_1 and D_4 are total ejection duration and D_3 and D_2 are total sweep duration, in sampling period T_P, for convective and stable situations, respectively.

3. Results and Discussion

The intermittent function was applied to the seven files selected. A frequency distribution was built with the duration of all CS detected. That distribution is, as it was already noticed by Krusche and Oliveira (2004), a decreasing exponential. The larger values of duration will contaminate the average characteristics of the CS. Therefore, CS with a duration greater than 40 s will not be consider in the present analysis. That corresponds to 13% of the total detected CS, and to 31% of reduction of the average duration.

Table 1. Characteristics of Turbulence and of CS. Duration is the size of the dataset, U and DU are thr average wind velocity and direction, respectively; I_{tub} is the intensity of turbulence; ζ is the stability parameter; u_* is the friction velocity. The CS are characterized by their average number, duration, intensity and intermittence factor γ.

File	General						Coherent Structures			
	Duration (s)	**U(m/s)**	**DU(°)**	**I_{turb}**	**ζ**	**u_*(m/s)**	**Number**	**$Duration_{CS}$(s)**	**I_{CS} (°C)**	**γ**
1	800	3.2	26	0.10	-0.02	0.26	23	17.8 ± 8.76	0.06 ± 0.029	0.51
2	869	3.4	21	0.06	-0.05	0.20	22	18.0 ± 7.82	0.05 ± 0.020	0.45
3	581	3.0	30	0.07	-0.10	0.15	10	17.0 ± 8.79	0.04 ± 0.022	0.29
4	869	2.2	41	0.13	-0.04	0.25	24	16.7 ± 9.25	0.06 ± 0.034	0.46
5	869	2.2	47	0.09	-0.83	0.12	17	17.9 ± 8.21	0.20 ± 0.092	0.35
6	869	1.6	39	0.16	-0.48	0.14	10	19.5 ± 7.07	0.22 ± 0.108	0.22
7	870	1.6	35	0.12	-0.23	0.20	13	21.0 ± 9.00	0.11 ± 0.120	0.31
						Average	17	18.3	0.11	0.37

The main characteristics of the CS detected are presented in Table (1). They are the average number of CS, their average duration for each period, and their average intensity, which is define as the height of the CS. The intermittence factor, which is the fraction of the series occupied by the CS, is also shown. Along with the CS results, some characteristics of the turbulence during each measurement period are also present in table (1). The intensity of turbulence is evaluated as proposed by Stull (1988), it has to be smaller than 0.5 for the Taylor's hypothesis to be valid. The stability parameter ζ is equal to z/L, where z is the measurement height (10 m) and L is the Obukhov length. The friction velocity u_* is a typical velocity for the Surface Layer. Both u_* and L were calculated according to Stull (1988).

Since the larger CS detected were neglected, the average duration and the intermittence factor are smaller than previous calculated, while the CS intensity is smaller by an order of magnitude if compared to the results of Machado and Krusche (2000a). The later is probably a characteristic of this particular day, while the former is a consequence of the range of CS sizes that were chosen. There is little or no relation to the general characteristics of the turbulence presented.

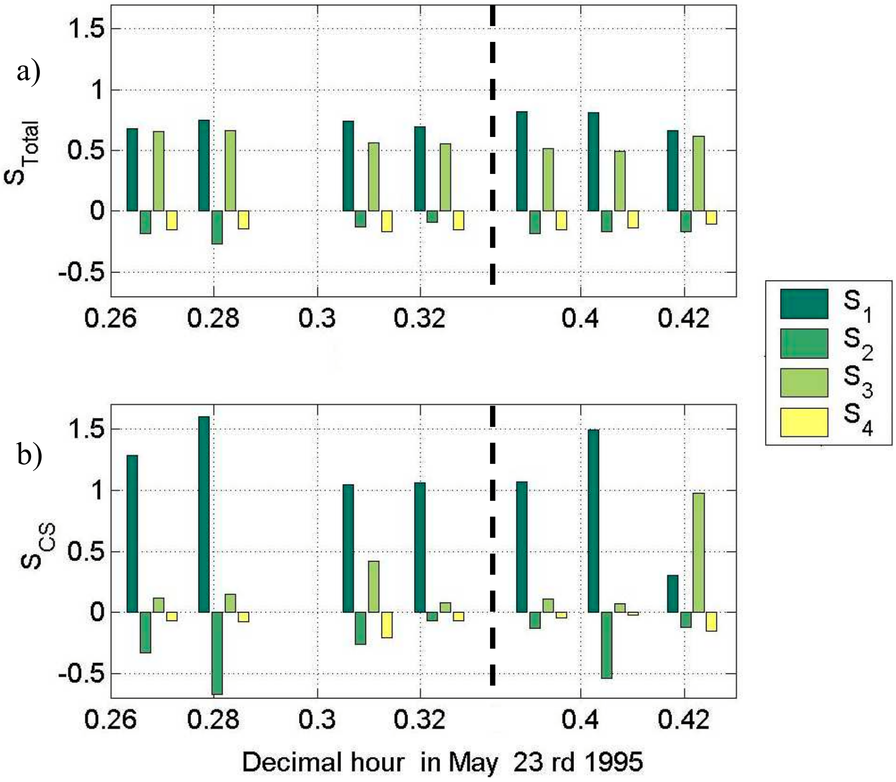

Figure 2 a) Stress fractions for whole dataset, and b) for coherent structures detected in datasets, during the convective period, where S_1 corresponds to ejections, S_3 is associated to sweeps, and S_2 and S_4 define interactions. Decimal hour is when the measurement started, first dataset at 6:26 local time, last one at 10:07 local time.

The next procedure consists in compare the quadrant analysis applied to the whole dataset to the one applied to the CS data. The results are shown in Fig. (2). Since the stability condition of the period under study is unstable, the stress fraction shows the larger contribution to the turbulent fluxes is due to ejections, followed by sweeps, while the contribution of the interactions is negative and small . When only the CS are considered, there are two remarkable effects: the ejections dominate and there is significant contribution due to interactions of the second sector, which are due to positive vertical velocity fluctuations. For the period analyzed, another interesting result is clear in the last dataset, where the larger contribution is due to sweeps, which is due to negative vertical velocity fluctuations. Since most of the CS is associated to positive vertical velocity fluctuations, which is clear in the other datasets, something unique is occurring at that moment, which is not detectable by analysis of the average characteristics of the CS, shown in Tab. (1). Therefore, that aspect will deserve further investigation.

The duration of events for the complete datasets is larger for sweeps than for ejections, due to the vertical velocity skewness during convective conditions. The larger CS duration are those of the ejection sector, except for the last file, which has a strong contribution due to sweeps. Those characteristics are present in Fig. (2). Therefore, the duration of events for CS corroborate the slow raising movement peculiar to them. The strong contribution due to sweeps in the last file must be further investigate.

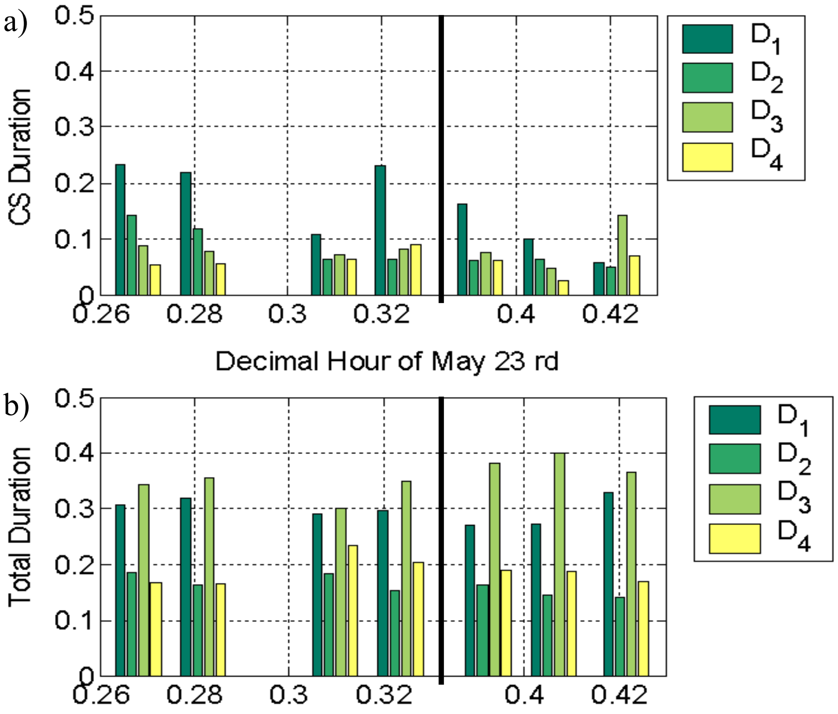

Figure 3 a) Duration for coherent structures detected in datasets, and b) duration for whole dataset during the convective period, where D_1 corresponds to ejections, D_3 is associated to sweeps, and D_2 and D_4, to interactions. Decimal hour is when the measurement started, first dataset at 6:26 local time, last one at 10:07 local time.

4. Conclusions

The chosen quadrant analysis provided a new insight of the turbulent flux contributions due to coherent structures, which were detected by intermittent function. It demonstrate that the CS contribution to the sensible heat turbulent fluxes is associated mainly to the quadrants related to ejections, both when the stress fractions and the duration are analyzed.

Moreover, there is no clear relation between the CS flux variation and the average characteristics of the CS, such as number, duration, intensity, and intermittence factor. Nevertheless, this result may be due to the small number of files analyzed. In one case, the larger CS contribution to the fluxes was related to sweeps. That result also deserves additional investigation.

Hence, the analysis should be extended to a larger set of measurements, but it has already provided useful information about the CS contribution to the turbulent fluxes.

5. Acknowledgement

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