On the characteristics of formation of coherent structure and turbulence in a dense forest of land measuring up to 80m in height: Project ATTO - CLAIRE - IOP1-2012

Newton Silva de Lima CEULM/ULBRA, Julio Tóta UEA/INPA, Maurício José Alves Bolzan UFG, Alan dos Santos Ferreira CEULM/ULBRA, Kaio Rafael de Souza Barbosa UFAM, Matheus da Rocha Pietzsch CEULM/ULBRA, Karyane Meazza CEULM/ULBRA, Ingrid Yumi Antonaccio Nomura CEULM/ULBRA.

Abstract

The characterization of formation of coherent structure by means of momentum transport and heat, above and within the canopy of an upland forest, is described here using as primary focus turbulent flow the vorticity of the flow through the quadrant analysis and the Morlet wavelet transformed into power spectrum for the temperature. The identification of vorticity and coherent structure for the studied levels were observed, with the "background" tower of 84 m, the intensive observation period - 1 (IOP-1/2012), in the forest of SDR - Uatumã - AM - Brazil.

Keywords: quadrant analysis, Morlet wavelet transform, vorticity.

Introduction

Several studies have targeted the development and dynamics of coherent structures in the boundary layer resulting from instabilities caused by varying the flow rate (*momentum*, heat, humidity and CO_2) which constitutes the dominant agent in the production of turbulence. These formations consistent with high Reynolds number extract kinetic energy from the mean flow and dissipate into small eddies (Wyngaard, 2010). Its shape and intensity depend on the structure of the main flow. According to Holmes et al. (1996), Liu (1988) identified the emergence of the concept of coherent structures in turbulent flow at the end of 1930. Townsend (1956) presents analysis on the speed and scale of coherent structures in various shear flows. LeMone, 1973, in the boundary layer meteorology the coherent structures tend to be called secondary flows. Examples include "convective rolls," large, counter-rotating, horizontal vortices may be visible through the "cloud streets". However, mechanisms for producing instabilities of coherent structures (CE) has broad-spectrum in the literature within the spatial-temporal oscillatory processes associated with turbulent vorticity.

We present an overview of the field experiment within the project ATTO-CLAIRE, the methods used, and particularly, the first results in Intensive Observation Period (IOP-1) between February and September 2012. As regards to the analysis of formation of coherent structures and their implications for (i) the structure of the turbulent exchange through the wavelet transform in (ii) method for analysis of flows between momentum and heat, (iii) the turbulent transport vorticity.

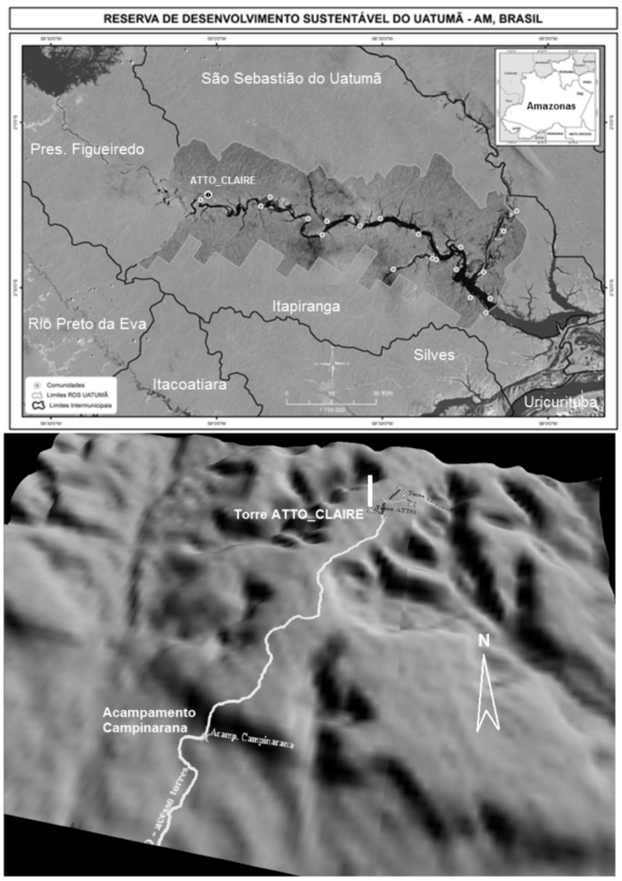

Figure. 1. Map of Sustainable Development Reserve Uatumã - AM, Brazil. Topographic location of the tower ATTO_CLAIRE Project (IOP-1), determined by the *Shuttle Radar Topography Mission* (*SRTM*). (UEA_INPA_LBA_MAX PLANCK, NASA, 2012).

Methods and Materials

Description of the experimental site

The site of the experiment ATTO-CLAIRE, is located in Sustainable Development Reserve (RDS) Uatumã in Uatumã São Sebastião, Amazonas State - Brazil ($2^0$8'32 .42 "S; $59^0$0'3 .50" W, ALT 131 m) (Fig. 1), the mean tree height between 40 and 45 m leaf area index (LAI) which this area is around 5-6 $m^2.m^{-2}$ (Oliveira, 2008): measures the integral structure characteristic of turbulent during the seasons: rainy and dried (IOP-1, 2012), were performed with three 3D ultrasonic anemometers (Solent, Gill Instruments, UK), three 2D-WindSonic ultrasonic anemometers (Gill Instruments Ltd, UK) with four ultrasonic anemometers 2D & Wind Speed Direction Sensor (Gill Instruments Ltd, UK). The tower of this experiment has the following characteristics: height of 84 meters and triangular cross-sectional area of 0.156 m2. The devices were placed at the following times: 78 m, 41 m to 30 m for the Wind Master, 57 m, 70 m 62 m to the Met Pack, 23 m, 36 m, 45 m and 50 m for the Sonic Wind. The predominant wind is from the northeast.

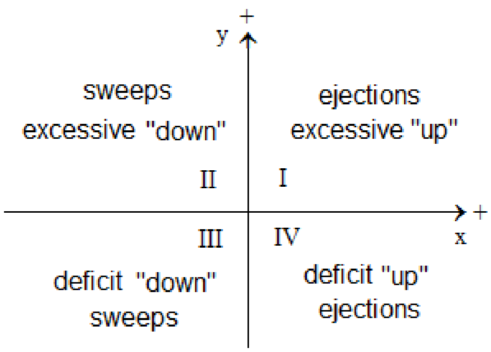

Figure 2: Definition of ejections and sweeps to heat flow (unstable conditions) and momentum (x = w and y = u; in general). (Antonia, 1981; Caramori et al. 1994; Katul et al. 1997; Bolzan et al. 1998).

Quadrant Analysis

Antonia (1981), Raupach (1996) and Foken et al. (2012) studies suggest that turbulent flow events associated with ejections or sweeps vortices characterized by coherent structures may be done by analyzing quadrant. The prior art method described by this Caramori et al. (1994), Bolzan et al. (1998) and Prasad et al. (1998) says that in the x-axis, x = u and on the ordinates axis, y = w or, x = y = T w (where u is the fluctuation of the turbulent wind speed along the direction of flow; w a fluctuation of vertical velocity and T is the temperature fluctuation), according to what we want to study. Caramori et al. (1994) clarifies that the quadrants are best settings when identified: excessive "up" a studied flow, excess or "down," or deficit "up" and "down" as shown in Figure 2.

Wavelet Transformed

The wavelet transformed (WT) is used to study the variability of the energy per scale (frequency) and time, ie allows capturing the oscillatory behavior data (Daubechies 1992; Farge 1992; Kumar and Foufolla 1997; et Dominges al. 2003). This is achieved by viewing a three-dimensional diagram in a series of chart-temporal, where the ordinate axis locates the frequency scale, the abscissa the time scale, and the third axis the intensity of energy (usually represented by color spectrum) Bolzan, (2000, 2006). Thus the term wavelet refers to a set of functions with the form of small waves generated by dilation, $\psi(t) \rightarrow \psi(2t)$, and translations, $\psi(t) \rightarrow \psi(t+1)$ a function generator based on simple $\psi(t)$, called wavelet-mother, $\psi_{a,b}(t)$ (Bolzan, 2006). Imposing that its average energy is zero as the condition of admissibility of the function. Mathematically, the wavelet scale function a and position b are expressed by:

$$\psi_{a,b}(t) = a^{-1/2}\psi\left(\frac{t-b}{a}\right) \qquad (1)$$

where $\underline{a}$ and $\underline{b}$ are real and $\underline{a}>0$. Note that equations (1 and 2) $a^{-1/2}$, include the normalization term. The wavelet transformed is defined by:

$$(W_\psi f)(a,b) = \frac{1}{|a|^{1/2}}\int f(t)\psi\left(\frac{t-b}{a}\right)dt \qquad (2)$$

where the temporal function f (t) is the number of data to be analyzed. Note that Equations (1) and (2) are similar, the only difference is called the nucleus of the equations, that is, in the WT is given by a wavelet function.

Rotation and Vorticity

The study of fluid dynamics is complicated in general, when we try to explain, translate, rotate, and shear deformation of the drive of an air parcel, since everything happens simultaneously (Çengel and Cimbala, 2007; Schiezer, 1996, Fox and McDonald, 2001). Then it becomes preferable that the explanation desired happen in terms of rates. Then for an incompressible fluid and flow invicídio in two dimensions (R^2):

$$\frac{du}{dt} = -\frac{1}{\rho o}\frac{\partial p}{\partial x};\ \frac{dv}{dt} = -\frac{1}{\rho o}\frac{\partial p}{\partial y};\ \frac{du}{dt} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \qquad (3)$$

Assuming the equation of rotational momentum, the term gradient disappears. Then, taking $\frac{\partial}{\partial x}$, the second (3) less $\frac{\partial}{\partial y}$, first we obtain;

$$\frac{\partial}{\partial x}\left(\frac{dv}{dt}\right) - \frac{\partial}{\partial y}\left(\frac{du}{dt}\right) = 0. \qquad (4)$$

Expanding the total derivative, using the third term of (3), we obtain;

$$\frac{\partial}{\partial x}\left(\frac{dv}{dt}\right) - \frac{\partial}{\partial y}\left(\frac{du}{dt}\right) = \frac{d}{dt}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \qquad (5)$$

The vorticity in general is defined by;

$$\xi = \nabla \times \boldsymbol{u}; \qquad (6)$$

The vertical component is given as;

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}; \qquad (7)$$

A concept concerning the vorticity is the circulation. May be written around a closed curve "C," i.e.;

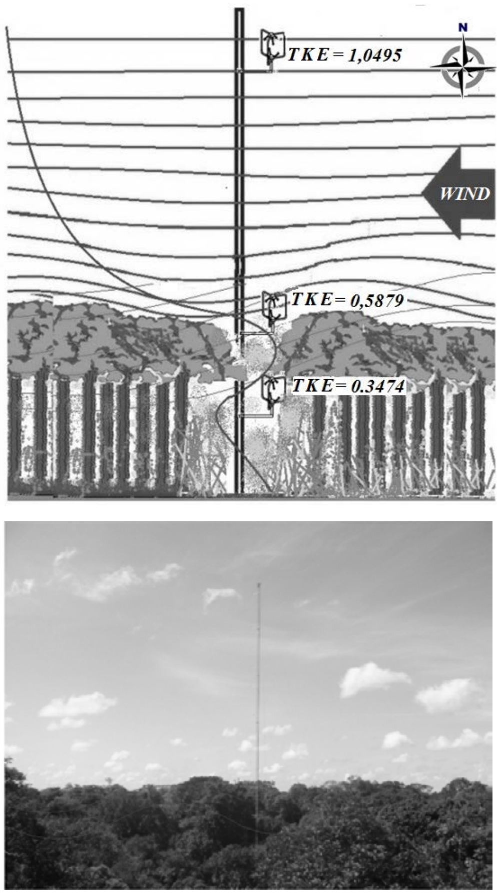

Figure 3: Schematic of the experiment ATTO_CLAIRE Version (2012 FEB 27/ 06:03:33 GMT) Picture of the tower (84 m), IOP-1 in the RDS - Uatumã - AM / Brazil. (Source: UEA_INPA_LBA_MAX PLANCK - 2012).

$$C = \oint_c u\, dl \qquad (8)$$

where the integral around the closed curve ("C") in the border area ("A") of the vector field $\vec{u} = u\vec{i} + v\vec{j}$ and linear increment "dl" along "C". Can be written, from Stokes' theorem,

$$C = \oint_c \boldsymbol{u}\, d\boldsymbol{l} = \int_A (\nabla \times \boldsymbol{u}) \cdot \vec{z}\, dA = \int_A \zeta\, dA \qquad (9)$$

Since the area element dA and A the area circled by "C". This circulation along the closed curve is equal to the integrated vorticity enclosed by this boundary.

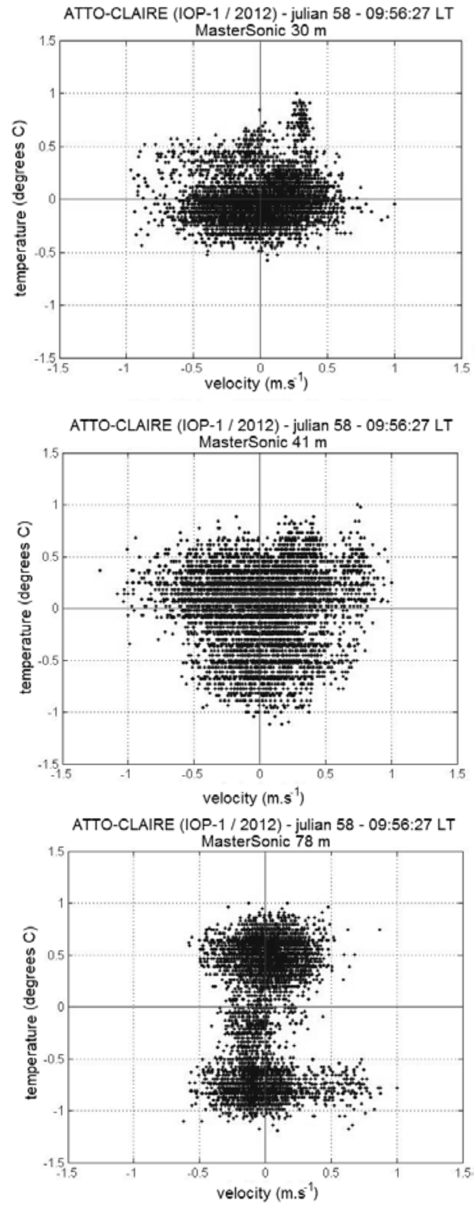

Figure 4: Coherent structures of evolution in levels different three (30 m, 41 m, 78 m), on experiment (Julian 58) ATTO_CLAIRE - IOP-1/2012. (UEA_INPA_LBA_MAX PLANCK, 2012).

Discussion and Results

In Figure 3, we see information on 27th February 2012 (06:03:33 UTC), on experiment ATTO_CLAIRE (IOP-1), the "background" of these data shows an increase of turbulent kinetic energy (TKE) for maintaining the turbulence level three coherent, registered in the 3D ultrasonic anemometers. From the lowest level, growth occurs in approximately 1.7 times higher than the second level and approximately 3.0 between the first and third levels, with reference to the base of the tower. But this dynamic, turbulent coherent indicates the formation of coherent structures in three levels, as evidenced in the coupling, shown by quadrant analysis in Fig.4. As these formations like "rolls", paired and torn (Fig. 4), as discussed by Hussain (1986). In Schoppa and Hussain, (2002), report that structures with this format pairing vorticity and phase behavior can be split into two or more parts, as can be seen in Fig.4, although CE in terms of vorticity is still consistent focus of many controversies. Naturally, one CE is a statistical entity, the result of the average phase alignment assembly of a structure containing a large number of outputs, (Hussain, 1986), noted in Figure 4.

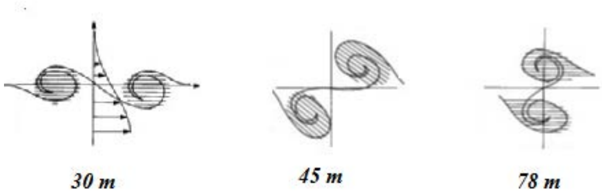

Figure 5: Pairing of vorticity and phase coherent structures, represented here by interpreting the behavior seen in Figure 4, by quadrant analysis at their heights respective (ATTO_CLAIRE-IOP-1/2012). (Hussain 1986; p. 333).

The effort to understand the structures of Figure 4, from Hussain, (1986), Bolzan, (1998), for clusters predominant (wT), it is possible for performing coherent vorticity, which is shown in Figure 5. However, a better explanation of these structures for different levels may be further characterized by the panel of Figure 6, for the same time in Figures 3 and 4, which reflect the embodiments previously seen, now on Wavelet Transforms to estimate the variability of the energy scale (frequency) and time, i.e. the oscillatory behavior allows capture of data frequency and time signal atmospheric (Torrence and Compo, 1998, Flinchem and Jay, 2000).

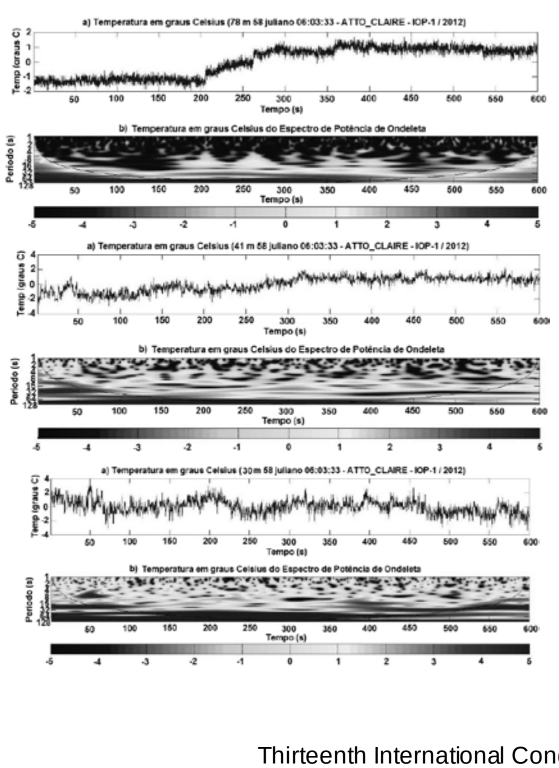

Figure. 6: Panel at levels three (78 m, 41 m, 30 m) Julian 58 / 2012 at day (06:03:33 GMT) on ATTO_CLAIRE-IOP-1/2012 experiment), time series of temperature of 600 s, coupled the power spectrum of the wavelet temperature. (UEA_INPA_LBA_MAX PLANK, 2012).

The instability seen in the series of temperatures (600 s) and the power spectrum of the wavelet temperature, Fig 6, is nonlinear nature of the flow inside the turbulent flow in the boundary layer surface, which can have several causes: (a) the existence of mechanism of action, in each of the episodes related, which is the non-stationarity of turbulent flow at the levels studied, (b) the position of the coherent structures that support the floating ripple is highly variable, so that the instrument in the position described, identifies this structure, with difficulty of interpretation, within the coherent flow, (c) the CE fluctuating occupies only a small fraction of the total column of atmospheric air, with finite wavelength and a possible surface layer supercritical (Hussain, 1986); (d) the wind force in the process flow above and within the canopy causes other forms of non-coherent turbulence which may invade the coherent band of turbulence by forcing the non-stationarity of the flow motion. Thus, the best interpretation was by Morlet wavelet transforms to the power spectrum, since it functions appropriately for non-stationary signal atmospheric (Torrence and Compo, 1998). In Figure 6, it is observed in the level of 30 m, information about formation of coherent structures in the parameter period - time, within the period of 4 to 8 sec (time of 45 to 60s); 8-16 s (Time 220-250 s) and from 16 to 32 s (time 350-450 s). In the 41 m level, coherent structures are identified in periods of 16 to 32s, time (300-320 s, and 450-470 s). At the level of 78 m in the period 4-64 s (time 200-300 s), then the momentum and heat transport by coherent structures are visualized within the timing set of Figs. 4, 5 and 6.

Conclusion

The results of the experiment exposed ATTO_CLAIRE (IOP-1/2012), are in agreement with those described by Hussain, (1986), Katul et al. (1997) and Bolzan, (1998), according to which, when there is variation of the conditions of stability, there is influence of the duration of the coherent structures associated with ejections, notoriously visible in Figs. 4 and 6. In decomposition into quadrants of sensible heat flux was noticeable differences in the formation of aggregates at different levels, which derive from the regime of non-stationarity and vorticity within the quantitative processes in the formation of coherent structures, which seems to reflect the local weather conditions and hourly observation. The consistency of geophysical signal analysis by wavelet transforms, this research involved demonstrated robust identification of coherent structures such as "rolls" in the flow studied, with also demonstrated by Bolzan (2000, 2006) and Foken (2012).

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