Comparing spectra and cospectra in nearly flat terrain with those in the roughness sublayer above the Amazon Forest

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1. Introduction

We analyze spectra and co-spectra of surface- and roughness sublayer turbulence from data set obtained during the LBA-ECO project at the Santarém study area. Three eddy flux towers operated continuously between 2000 and 2005; two are projected to continue. One is located in the old-growth forest; a second is in an area of the same forest subjected to selective logging. The third tower flux is located in a cleared area that underwent changes the agriculture practices (from pasture to rice to soybean cultivation). Spectra presented here are derived from data collected from the old growth site and from the cleared area, here referred as the 'pasture' site. At the pasture site (3.16^o S, 54.95^o W) data were collected at 10Hz by a Applied Technologies, Inc., SATI 3D sonic anemometer located 8.75m above the ground. At the old growth site (2.85^o S, 55.03^o W) data were collected at 5Hz by a 3D Gill sonic anemometer located at 58m above the ground. The average canopy height is 45m.

2. Methodology

Spectra and co-spectra were determined using time series with 2^{15} data points, i.e. approximately 30 min. The windows are centered at a given data point which advances with 3-min time steps for each series. Before the analysis, the individual wind vectors were rotated into the mean wind direction in such a way that $\overline{v} = \overline{w} = 0$. In the second phase, mean values, micrometeorological parameters, standard deviation of turbulent variables, spectra and co-spactra were calculated. A data quality analysis was applied to detect any spikes, kinks or missing portions in the data. In this paper we analyze only those sets for which $-2 \le z/L \le 2$.

3. Results

The spectra presented in this section were calculated for time series with 2^{15} data points, i.e. approximately 30 min. They are normalized by the friction velocity and by the non-dimensional dissipation rate, $nS_\alpha \big/ u_*^2 \phi_\varepsilon^{2/3}$ ($\alpha = u, v, w$) and the frequency is scaled by U/z. The results were separated according to the wind speed (U < 1m/s and U > 1m/s). The nocturnal spectra are distinct by six classes of stability ($0.0 < z/L < 0.1$; $0.1 < z/L < 0.3$; $0.3 < z/L < 0.5$, $0.5 < z/L < 0.8$, $0.8 < z/L < 1.1$ and $1.1 < z/L < 2.0$) as well as the diurnal spectra $-0.1 < z/L < 0.0$; $-0.3 < z/L < -0.1$; $-0.3 < z/L < -0.5$, $-0.5 < z/L < -0.8$, $-0.8 < z/L < -1.1$ and $-1.1 < z/L < -2.0$).

3.1 Spectra of S_w

The spectra of the vertical component of the velocity present the most distinguishing feature. There are a well defined peak for all stability classes and wind speed both for the pasture site and above the forest canopy. Figure 1 shows $nS_w \big/ u_*^2 \phi_\varepsilon^{2/3}$ for wind speed higher than 1ms^{-1} and weakly convective conditions. The red line is the corresponding -2/3 Kolmogorov's law for the inertial sub-range. It is important to note that the position and the value of the peak have near the same values

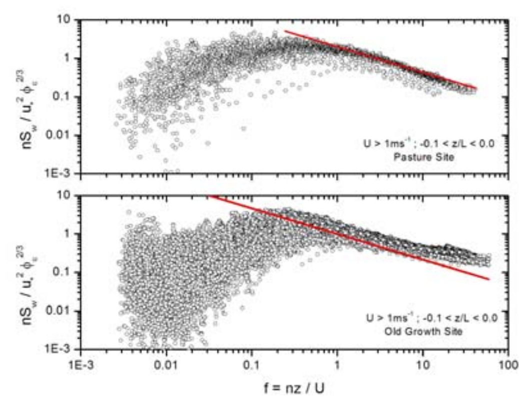

Figure 1 Non-dimensional spectra of vertical velocity for wind speed higher than 1ms^{-1} and weak convective conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.

3.1 Spectra of S_u and S_v in stable conditions

We present first analyses of nocturnal time series. Figure 2 and 3 display the spectra of longitudinal velocity for wind speed lower than 1 ms^{-1} for weak and very strong stability.

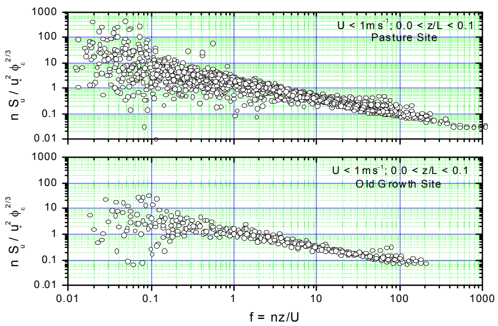

Figure 2 Non-dimensional spectra of longitudianl velocity for wind speed lower than 1ms^{-1} and weak stable conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.

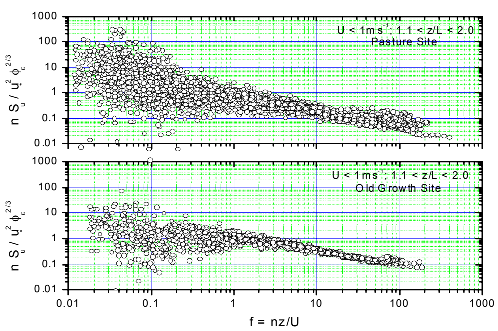

Figure 3 Non-dimensional spectra of longitudianl velocity for wind speed lower than 1ms^{-1} and strong stable conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.

Under weak winds a pronounced spectral peak is not observed in the surface layer above the pasture site. However there is a some evidence that the spectral peak appears above the forest (the same results are presented for the lateral spectra – figures not shown). In the pasture site and with small contribution of mechanical production the mixing of turbulence and other atmospheric mean motions are not distinguishable in the spectral analysis. Under more windy conditions (U > 1ms^{-1}) the spectral peak is clearly observed both over the pasture site and above the canopy layer. This result is for weak stable conditions in Figure 4. From the same figure we note two important results: a) over the forest the more energetic eddies are smaller than over the pasture site and b) over the pasture the spectral peak is at higher frequency than that over the forest.

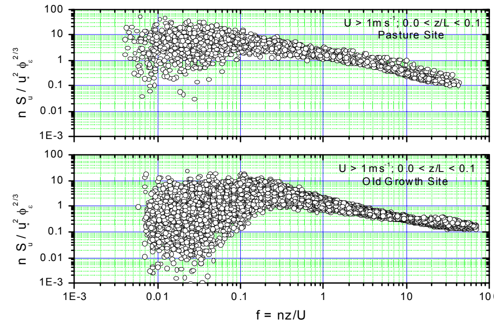

Figure 4 Non-dimensional spectra of longitudianl velocity for wind speed higher than 1ms^{-1} and weak stable conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.

3.1.1 S_u and S_v in convective conditions

The spectra of horizontal turbulent velocities under convective conditions do show a well-defined spectral peak. In this case, the peak may be associated with the height of the boundary layer z_i (Kaimal and Finnigan, 1994). In the convective boundary layer large-scale motions, which do not scale with z should shift the spectral peak to lower frequencies. To seek the presence of the spectral peak at lower frequencies the spectra were then calculated with longer time series. Results showed in this section is for time series with 2^{17} data points, i.e., approximately 2 hours. To have confidence in this analysis we use data collected between 1100 and 1700 LT. The maximum heat flux, for all days analyzed, occurs near 1300 LT. There is a decreasing in the averaged values with the increase of the window used for the analysis. This means that the number of stability classes for bigger window is lower than that one obtained for smaller windows. With a 2h window the stability classes for weak winds is limited by $-0.5 < z/L < 0.0$ while for windy conditions it is limited by $-0.3 < z/L < 0.0$. In other words: for this window the results here presented are separated into three stability classes for $U < 1\,\mathrm{m/s}$ and in two classes for $U > 1\,\mathrm{m/s}$.

Figures 5 and 6 show the spectra for low and high wind speeds, respectively. A spectral maximum is not defined for weak mechanical forcing. Probably under only thermal forcing the spectral peak are located at frequencies not estimated within the 2h window. On the other hand for wind speeds higher than

1m/s the presence of the spectral peak is nearly defined. At the lower frequencies it is observed an increasing spectral values and we speculate that this increase is due to the presence of other meteorological events that contaminates the energy of the atmospheric movements.

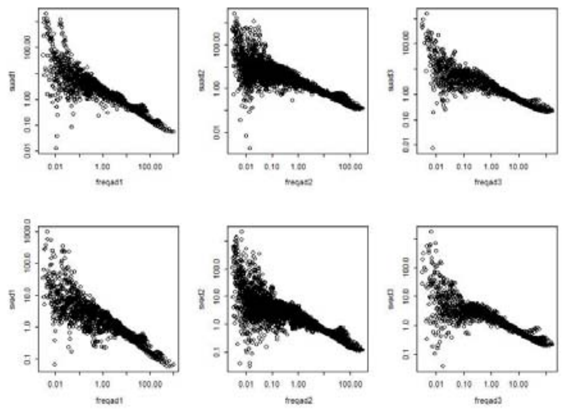

Figure 5 – Non-dimensional spectra of the longitudinal (top) and lateral (bottom) velocity component for weak wind and convective conditions. Stability parameters are (for left to the right) $-0.1 < z/L < 0.0$ *;* $-0.3 < z/L < -0.1$ *and* $-0.5 < z/L < -0.3$*. Spectra calculated with 2h window.*

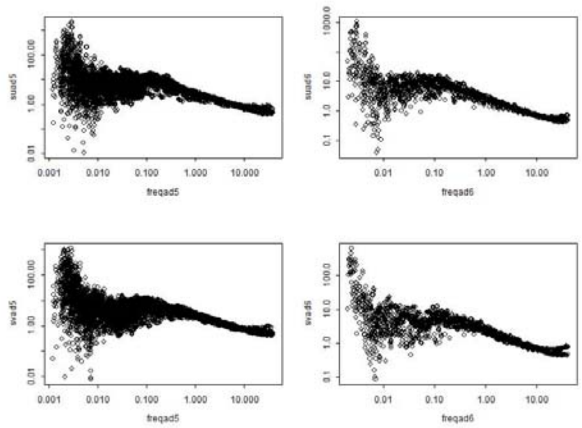

Figure 6 – As figure 5 for wind speed higher than $U > 1m/s$ *Stability parameters are (for left to the right)* $-0.1 < z/L < 0.0$ *and* $-0.3 < z/L < -0.1$*.*

3.2 Cospectra

Cospectra of $w\theta$ calculated for 30m time series were separated according to wind speed and stability. In the following figures we display only the cospectra for windy conditions both for nocturnal and diurnal periods and near neutral stability. It is interesting to note that the cospectral curves for the roughness sublayer above the canopy are more peaked when compared with those obtained for the pasture site. Sakai et al. (2001) found a similar result.

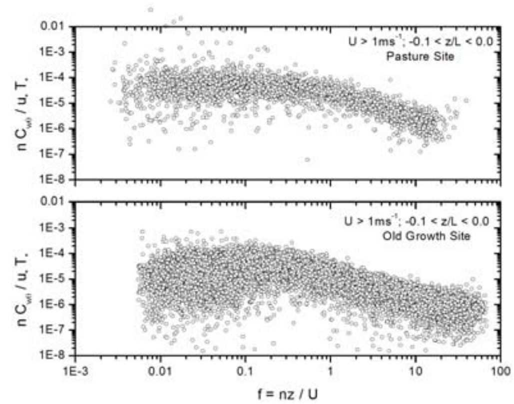

Figure 7 Non-dimensional cospectra of vertical velocity and temperature for wind speed higher than 1ms^{-1} *and weak convective conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.*

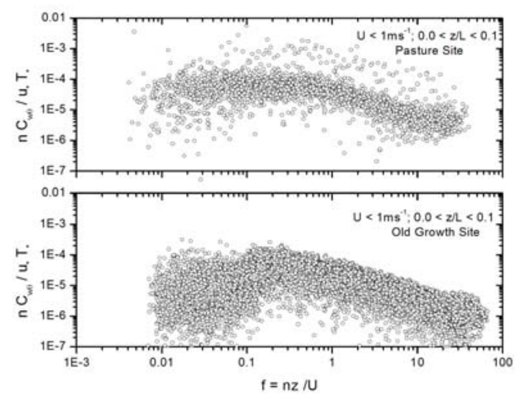

Figure 8 Non-dimensional cospectra of vertical velocity and temperature for wind speed lower than 1ms^{-1} *and weak stable conditions. Top panel is for the pasture site. Bottom panel is for the old growth site.*

4. Conclusions

It was showed that the spectra of vertical component of the turbulent velocity over the near flat surface and in the roughness sublayer above the Amazon Canopy has the same behavior. The spectra of the lateral and longitudinal velocity components are not well defined for low wind speed and stable conditions. For windy conditions, i.e. U > 1ms^{-1} and stable conditions the spectral peak is presented over the canopy but it is not presented over the pasture site. It is speculated that mesoscale motions contaminates the turbulent spectra at similar frequencies. The corresponding spectra for convective conditions, when estimated over larger windows, have a well defined peak for wind speed higher than $U > 1ms^{-1}$. It was also showed that the cospectra of vertical velocity and temperature over the canopy is more peaked than the corresponding cospectra over the pasture site.

References

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ACKNOWLEDGMENTS

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