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TURBULENT CARBON EXCHANGE IN VERY STABLE CONDITIONS

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1. INTRODUCTION

Recent studies have shown that turbulent fluxes in very stable conditions can be determined by the use of the multiresolution decomposition (Howell and Mahrt, 1997; Mahrt and Vickers, 2005). These fluxes are very small in magnitude, and have a very short time scale, but are well behaved with proper calculation of the turbulence statistics. A cospectral gap has been shown to exist, clearly distinguishing the turbulent exchange from the larger-scale, more erratic mesoscale fluxes (Vickers and Mahrt, 2003).

In the present study, we use the multiresolution decomposition to look at carbon dioxide fluxes from a deforested site in the Amazon region. Previous studies have applied the technique for either momentum or sensible heat fluxes (Vickers and Mahrt, 2003; Mahrt and Vickers, 2005). The turbulent CO_2 exchange, however, may behave differently, happening on other scales and showing different dependences on stability and turbulent intensity. Moreover, the exact determination of nocturnal respiration rates is a very important problem for properly characterizing ecosystem carbon exchange, specially for those places where very weak turbulence is the common state of the nighttime surface layer. Therefore, the objective of this study is to identify the scales of the turbulent exchange of carbon in very stable conditions, and to infer how that knowledge will help to determine nighttime ecosystem respiration rates in those cases.

2. SITE AND DATA DESCRIPTION

The data used in this study were collected in Santarém, PA, Brazil, as part of the Large-Scale Biosphere-Atmosphere Experiment in the Amazon (LBA). The site is deforested and, at the period of the data used here, was a pasture used for cattle grazing (Sakai et al., 2004). The site has been operating continuously since 2000.

Deforestation leads to enhanced nighttime radiative loss at the surface. As a consequence, the nocturnal surface layer typically presents a very stable temperature stratification. It reduces nocturnal mixing in such a way that the commonly used eddy covariance technique is unable to provide estimates of the surface respiration rates. Substitution of the nights without enough mixing for those with similar surface conditions but stronger winds, often used to overcome this difficulty, is not possible in this case, because the strongly stable case happens in more than 90% of the cases. Sakai et al. (2004) report that during 98 % of the time the friction velocity is lower than 0.2 ms^{-1}, and during 82 % of the time it is lower than 0.08 ms^{-1}.

We will look at data from 62 nights from January to March 2001, which is during the wet season. The three wind components were collected at 10 Hz by a Sonic anemometer SATI/3K, located at 8.5 m from the surface. At the same height, CO_2 concentrations were measured by an infra-red gas analyzer Licor 6262.

3. RESULTS

The multiresolution decomposition was applied for 13.65-minute windows (2^{13} data points), which were then moved by 1 minute, and the process was repeated. The overlap between series was done to maximize the possibility of a given event being properly captured. All nights from January to March 2001 for which there were no instrumental problems were used, leading to a total of 31,750 time series analyzed. The wind was rotated for each time series, forcing the mean wind field to be in the *x* direction.

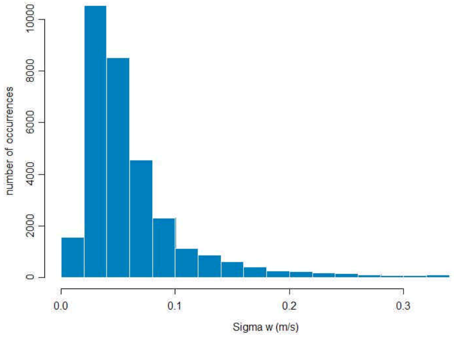

Figure 1. Statistical distribution of s_w for the time series analyzed.

We used s_w, the standard deviation of the wind vertical component to classify the data by turbulent intensity. The choice was made to avoid variables that depend on fluxes, which are difficult to be determined.

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In the vast majority of the cases, s_w was lower than 0.1 ms^{-1} (fig. 1).

One example is shown in figure 2. The turbulent activity was reduced along the entire night, as indicated by the vertical velocity that varied from –0.2 to 0.2 ms^{-1}. Intermittency occurred on this night, and is a common phenomenon at the site, leading to periods of extremely weak turbulence, such as the one represented by a colored stripe in figure 2, for which $s_w = 0.01$ ms^{-1}. The turbulent fluxes can be determined for this very stable series, using the multiresolution decomposition. They have very low magnitudes, but are well behaved, and a cospectral gap can be defined, which separates the organized turbulent fluxes from the more erratic, larger-scale mesoscale fluxes (figure 3).

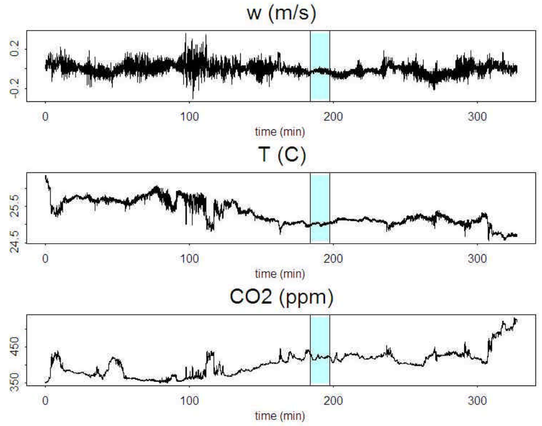

Figure 2. Time series of vertical velocity (upper panel), temperature (middle panel) and carbon dioxide concentration (lower panel) for the night 11 January 2001. The colored region indicates one very stable series.

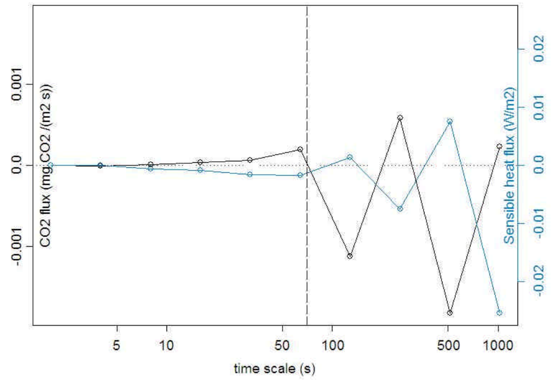

Figure 3. CO$_2$ flux (black, scale on left side) and sensible heat flux (blue, scale on right side) as a function of time scale, as determined from the multiresolution decomposition, for the very stable series indicated in figure 2.

The overall behavior indicates that the turbulent carbon fluxes are well behaved and scale well with turbulence intensity (figure 4, upper panel). For comparison, the sensible heat fluxes results are shown (figure 4, lower panel). There is a tendency for positive mesoscale fluxes for all classes of turbulent intensity, confirmed when the multiresolution decomposition is applied for longer time series (figure not shown). This feature, however, only appears after averaging for a large enough number of cases. Individual time series tend to show erratic mesoscale fluxes.

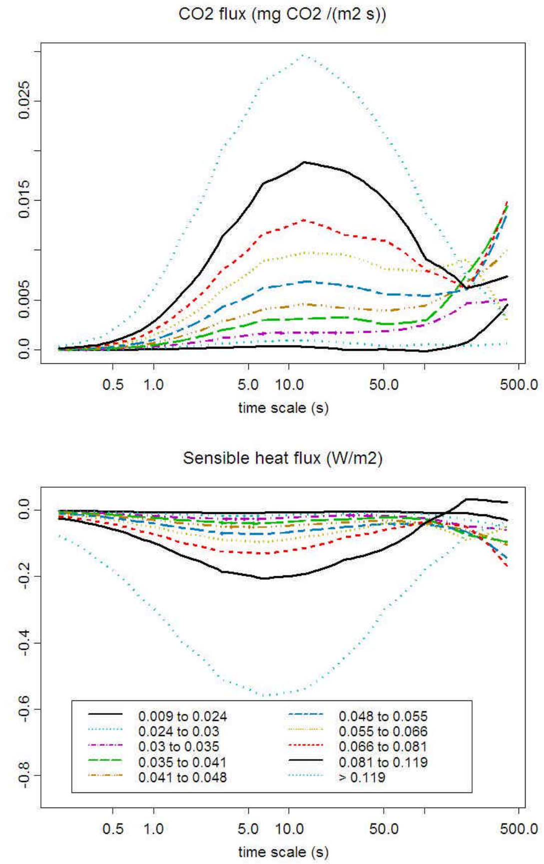

Figure 4. Carbon dioxide flux (upper panel) and sensible heat flux (lower panel) as a function of time scale. The different lines indicate different levels of s_w, as indicated by legend in lower panel.

The same behavior exists for the 10% most stable series (figure 5). The flux magnitudes are much smaller in this case but, nevertheless, the main characteristics, such as the cospectral gap, the well defined turbulent peak and the dependency on turbulence scale are preserved. Mesoscale fluxes appear to be more erratic than for the totality of the series but this can be a consequence of the smaller number of cases being averaged.

The turbulent transfer of CO$_2$ appears to happen at larger scales that that of sensible heat. The comparison of the cospectral peak time scale for each variable indicated this behavior (figure 6). For extremely stable conditions ($s_w < 0.02$ ms^{-1}), the two processes happen at similar and very small time scales. For more turbulent conditions, the time scale of the cospectral peaks of both fluxes starts to increase. For a wide range of conditions, the carbon flux peaks at a time scale (~15 s) appreciably larger than that of the sensible heat flux (~5 s). For enough turbulent conditions ($s_w > 0.2\,\mathrm{ms}^{-1}$) the two processes happen at similar time scales, again. Interestingly, the time scale for sensible heat flux remains the same for a wide range of turbulent intensities. The carbon flux cospectral peak time scale, on the other hand, shifts to smaller values for $s_w > 0.2\ \mathrm{ms}^{-1}$.

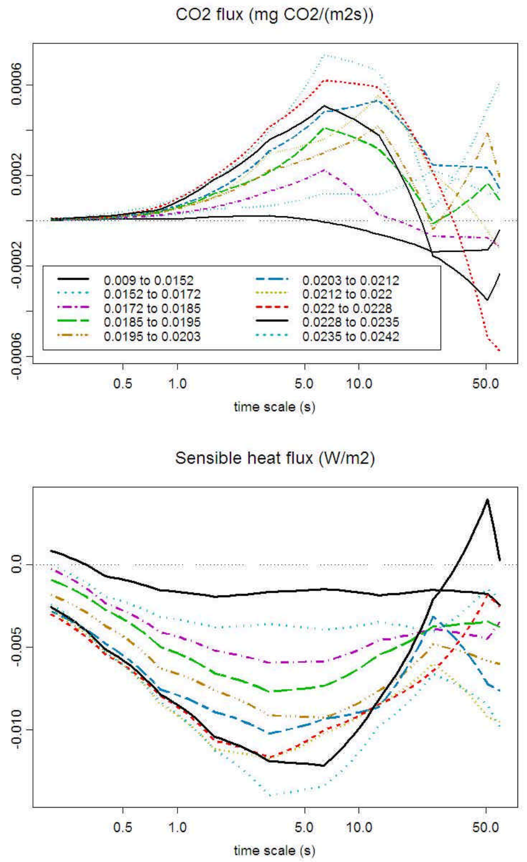

Figure 5. Same as figure 4, but for the 10% least turbulent series.

The turbulent fluxes determined by the integration of the multiresolution cospectra up to the cospectral gap scale shows a clear dependence on turbulence intensity. This is not the case for the fluxes determined from the eddy covariance technique, on which one computes the transfer up to a fixed scale, often accounting for mesoscale processes. For that reason, besides the larger variability, the eddy covariance fluxes also show larger magnitudes. The difference is enhanced for very stable conditions, as in this case the scale of the turbulent transfer is greatly reduced to the order of seconds.

There is a turbulence intensity threshold above which the carbon dioxide flux seems to reach a constant value. This indicates the condition when the ecosystem respiration rate is fully transferred to the upper atmosphere by the turbulent flow. For the period studied, it happened for a very small portion of the data, in agreement with the results from Sakai et al. (2004). From figure 7, one can assume the threshold to be $s_w = 0.15\,\mathrm{ms}^{-1}$, which means that in 94% of the cases, the turbulence is not able to transport the surface-emitted carbon.

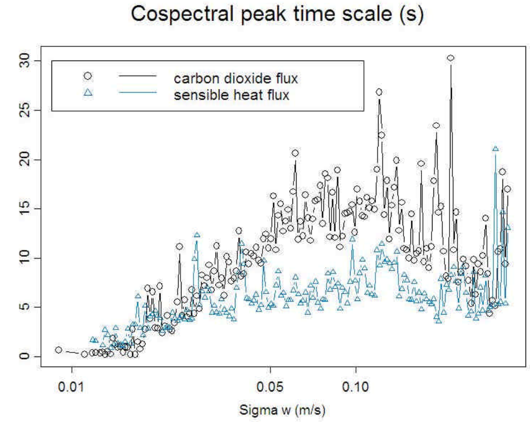

Figure 6. Time scale of the cospectral peak as a function of turbulent intensity

5. CONCLUSION

The present study showed that the turbulent carbon fluxes can be properly determined using the multiresolution decomposition. Time series that are commonly discarded for low turbulence levels contain the information on CO_2 fluxes, as long as they are determined using the appropriate time scale.

To extend these results and apply the technique for the estimation of ecosystem respiration rates, a number of steps still need to be achieved. First, the consistently positive mesoscale fluxes shown in figure 4 deserve further analysis. They suggest that larger-scale processes may be transporting an appreciable portion of the surface emitted carbon. These processes need to be identified. Second, it is important to determine the storage terms and to infer how much of the surface emissions simply accumulates locally. Finally, the results need to be extended for the dry season, which tends to be even more stable.

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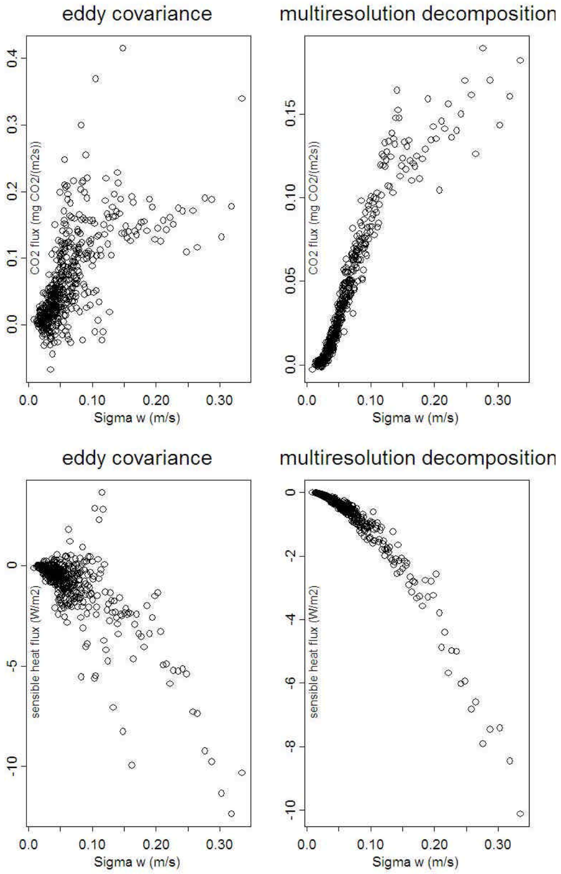

Figure 7. Comparison of the turbulent fluxes estimated using the eddy covariance technique (left panels) and using the multiresolution decomposition integrated up to the cospectral gap scale (right panels). Upper panels show carbon dioxide flux and lower panels show sensible heat flux.

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