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INTERMITTENCY AND THE SURFACE EXCHANGE OF SCALARS AT THE NOCTURNAL BOUNDARY LAYER

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1. Introduction

The determination of nocturnal surface fluxes in low wind conditions is a major problem for micrometeorological studies. The eddy correlation technique, extensively used in field measurements becomes inappropriate if not enough turbulent activity exists. At the same time, the phenomenon of turbulence intermittency is responsible for the existence of localized events of short duration for which a large fraction of the total nighttime scalar exchange occurs. Even though appreciable progress has been made towards a good understanding of this phenomenon in recent years, the near-random character of intermittent exchange makes the determination of surface fluxes under these conditions a difficult task. The scalar flux within a certain intermittent event varies largely depending on the window used for the flux calculation. In many cases, events with very different time durations occur at the same night, and therefore, the proper determination of the surface flux would require averaging within data windows of different sizes for each event.

In this work, the surface exchange of temperature, moisture and carbon dioxide is analyzed at a micrometeorological tower at southern Brazil. Intermittent turbulence is a common occurrence at the location. The analysis shows how the determined fluxes vary with turbulence intensity and the estimation technique. A method for determining the surface fluxes using a variable window size is suggested. The results show that fluxes are maximized with this method, as it catches the exact exchange within intermittent events.

2. Site and data

Data were collected at a continuously measuring site, at Paraíso do Sul, RS (S 29^o 44´ 39.6´´, W 53^o 8´ 59.8´), in southern Brazil. The tower is a part of CT-HIDRO project, a Brazilian-wide study with the purpose of describing the surface conditions at different ecosystems in the country. It has been operating since June 2003 at a rice plantation. Rice is planted in October, and harvested in April. The soil humidity content is high most of the time, determining a Bowen ratio lower than 0.4. The tower is located at a flat site, with a hill at its northward direction. Turbulence is measured at the 10-m height by a Campbell 3-D sonic anemometer, and moisture and carbon dioxide turbulent fluctuations by an open-path LICOR 6556. Other measurements include the radiative budget components, soil temperature and moisture content at 5 levels, as well as slow response wind, temperature, relative humidity and pressure.

The data used in this study consists of 60 nights from June to November, 2003. The reason for the small number of nights used among the total available in the period is that only those for which all turbulent signals had a good quality during the entire period from 2100 to 0500 LST were considered. Surface flux evolutions were determined for every minute, for each night. Thirteen different window sizes were used for mean removal, in each case: 1, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5 and 30 minutes.

3. Intermittency

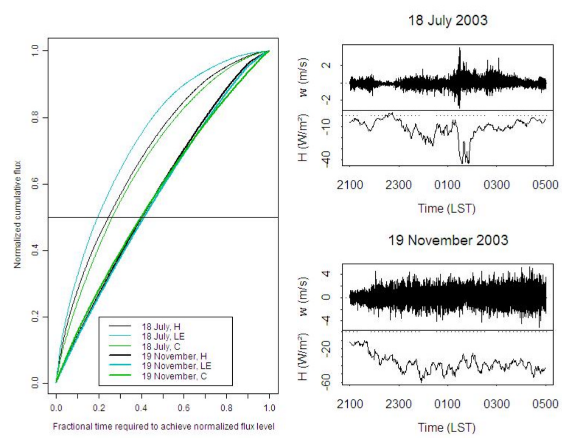

Figure 1. Left column: Cumulative fraction of total nighttime flux as a function of the fraction of the total time required to achieve the flux level. The different curves represent two different nights and the fluxes of sensible heat, latent heat and carbon dioxide, according to legend. Horizontal solid line represents the threshold of 50% of the total nighttime flux used to define the intermittency factor; Right column: temporal evolutions of vertical turbulent velocity and sensible heat flux at each of the nights.

The total of 60 nights used in this study covers both intermittent and non-intermittent cases. The quantification of intermittency is done following a method similar to those used by Howell and Sun (1999) and by Coulter and Doran (2002). For each night, the 1-minute surface fluxes of sensible heat, latent heat and carbon dioxide were smoothed using a 10-minute running mean and the resulting flux values were sorted. The intermittency factor (*IF*) is then given by the fraction of the total time required to achieve 50% of the total nighttime flux (figure 1). In the case of well-developed turbulence, the flux tends to be equally distributed over the time, so that IF approaches 0.5, like the 19 November 2003 night ($IF = 0.4$ for the

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sensible heat flux), shown in figure 1. If, on the other hand, most of the nighttime fluxes are restricted to specific events, as happens on intermittent nights, *IF* approaches zero. This condition is exemplified by the 29 July 2003 night ($IF = 0.15$ for the sensible heat flux), in figure 1.

In any night, the intermittency factor is very similar for the three different fluxes analyzed (sensible heat, latent heat and carbon dioxide flux), so that the analysis of the present study will consider only the *IF* values determined for the sensible heat flux. The *IF* values of the 60 nights range from 0.06 to 0.40.

4. Intermittency temporal scales

Intermittent events are highly localized both in time and space (Nappo, 1991; Coulter and Doran, 2002; Acevedo and Fitzjarrald, 2003). Their variable time scales and large surface fluxes suggest that the choice of data window used on the flux calculations during intermittent periods may be crucial for the determination of the mean nighttime surface fluxes under these conditions. For instance, the fluxes associated to an intermittent event in the night of 17 November 2003, largely vary depending on the window used for their determination (figure 2). The 20-min data window maximizes all three surface fluxes, and their magnitudes decreases remarkably for both smaller and larger windows, so that the inappropriate choice of the averaging interval may lead to an appreciable underestimate of the total nighttime surface flux.

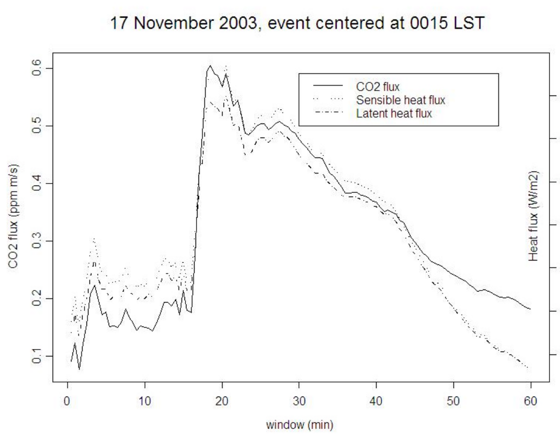

Figure 2. Surface fluxes variation as a function of window size for an intermittent event.

5. Nocturnal fluxes determination

With the purpose of finding the optimum flux, regardless of window size, flux matrices were determined for each night, showing the surface flux evolutions along the night, and its dependence on window size (figure 3). The optimized flux was determined from these matrices through the following iterative procedure:

- The maximum absolute flux value (*F*) for the entire matrix is found, and retained;
- The window size (*W*) that corresponds to *F*, and the time of its occurrence (*T*) are determined ;
- All values that are within $T \pm W/2$ are removed from the matrix;
- All values for which $T \pm W/2$ fall within the removed area are also removed from the matrix to avoid double counting any event;
- The maximum flux is found for the new matrix and retained, and the entire process is repeated until the entire matrix has been counted;
- The mean nighttime surface flux is determined as $\overline{F} = \sum (W_i F_i) / \sum W_i$, where F_i represents all the retained flux values and W_i is the respective window sizes. The value $\sum W_i$ has to equal the total time length of the series.

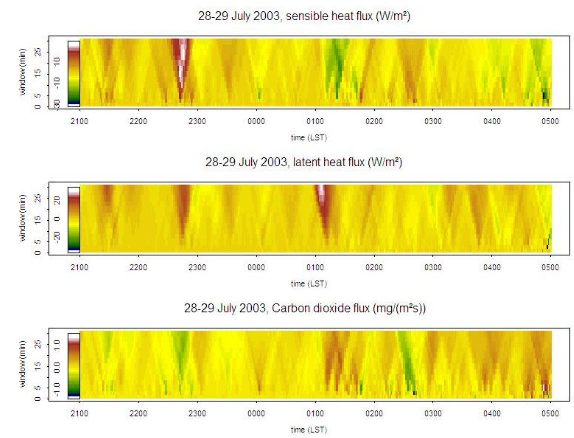

Figure 3. Surface fluxes as a function of local time and window size. Magnitude of the fluxes is given by grayscale on the left side.

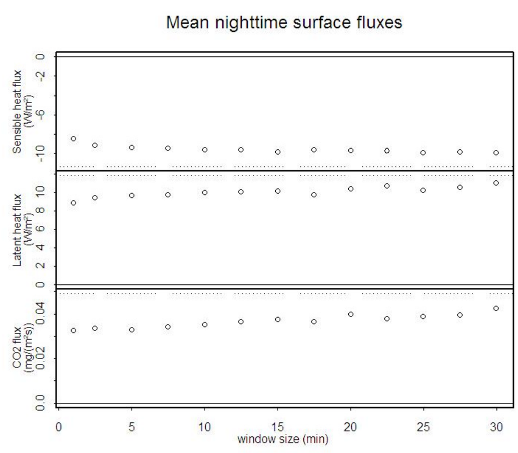

Figure 4. Mean nocturnal surface fluxes for all 60 nights as a function of window size. Upper panel shows sensible heat flux, middle panel is latent heat flux and lower panel is carbon dioxide flux. In each panel, solid line represents zero and dotted line is the mean flux calculated with the variable window size.

The mean nocturnal flux for all 60 nights, determined with the variable window, is larger than the mean flux with any fixed-window size. The mean fluxes, for all quantities, increase for longer windows (figure 4). For sensible heat, the mean variable-window flux (-11.3 Wm^{-2}) represents an increase of 34.1% of the mean 1-minute flux, and an increase of 14.1% of the mean 30-minute flux. For latent heat, the mean variable-window flux (11.8 Wm^{-2}) represents a 34.3% increase for the mean 1-minute flux, and a 7.7% increase for the mean 30-minute flux. Finally, the use of a variable window leads to a mean CO_2 flux (0.049 mg $m^{-2}s^{-1}$) that is 50.7% larger than the mean 1-minute flux and 15.7% larger than the mean 30-minute flux.

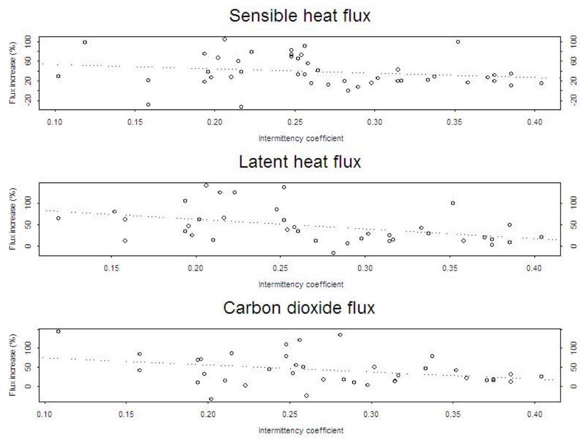

Figure 5. Variable-window flux increase compared to the 1-minute flux for each night, as a function of intermittency factor. Nights for which the mean fluxes with the 1-minute window were smaller than a threshold were not considered in the analysis, as it could lead to unrealistically large flux increases. The threshold used is 0.5 Wm^{-2} for sensible and latent heat fluxes and 0.002 mg $m^{-2}s^{-1}$ for CO_2 flux. In each panel, the dotted line represents a least-squares fit.

In the case of well-developed turbulence, the mean nighttime surface fluxes tend to be less sensitive to the window size, as the effects of intermittent events become less important. For this reason, the flux increase for the variable-window size is more significant for the more intermittent cases (figure 5). In all cases, the flux increase tends to zero as turbulence becomes more temporally homogeneous, i.e. as the intermittency factor approaches 0.5. For the intermittent cases, there is larger scatter in the data, but for the three quantities considered, there is a tendency of large flux increase under intermittent conditions.

6. Conclusion

Turbulence intermittent has been shown to affect the mean nighttime surface flux at a site. It is related to the fact that intermittent events have a defined time scale, so that the proper determination of their fluxes depends on averaging with a similar window size. In this work, we suggested a method for estimating the nighttime surface fluxes that accounts for the variability of the intermittent events time scale. A near 10% flux increase was observed using this new technique, as compared to the fixed window that maximized the surface fluxes.

Such results may lead to important changes in the regional surface fluxes estimations. Further work in necessary in that direction, but the present study gives indication that a proper characterization of nighttime turbulence intermittency may lead to appreciable improve in the total surface flux quantification.

Acknowledgements

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