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WAVELET ANALYSIS OF CARBON DIOXIDE FLUXES IN THE SURFACE LAYER ABOVE A DENSELY BUILT CITY CENTRE AT NIGHT

J.A. Salmond[1*], T.R. Oke[1] and C.S.B. Grimmond[2]
[1]University of British Columbia, Vancouver, British Columbia, [2]Indiana University, Bloomington, Indiana

1. INTRODUCTION

The thermal inertia, dryness and roughness of urban areas, especially in densely-built districts, typically results in the development of a weakly convective nocturnal surface boundary layer, often capped by a nocturnal inversion (Uno et al. 1992). Although this has significant implications for the dispersion of atmospheric pollutants, particularly from street canyons, few studies have focused on the development and characteristics of turbulence under these conditions.

Carbon dioxide (CO_2) is a comparatively inert gas which, in the absence of space heating sources and localized industrial emissions, is primarily emitted into the urban boundary layer at street level from vehicle exhausts. Here we use wavelet analysis to examine the hypothesis that CO_2 concentrations can be used as a tracer to identify characteristics of pollutant venting from street canyons into the nocturnal urban boundary layer (UBL).

2. EXPERIMENTAL AND WAVELET METHODS

A Licor–7500 and a RM Young 3-axis sonic anemometer were mounted on a tower located 44 m above the city center of Marseille (France) during the ESCOMPTE field project (Grimmond et al. 2002; Cros et al. 2002). Preliminary examination of the 10 Hz nocturnal turbulence data revealed intermittent bursts of CO_2, superimposed upon a more stable mean background concentration (Figure 1a). All times are given in Local Standard Time (LST).

This study uses the symmetric 'Mexican hat' wavelet to objectively isolate, and quantitatively analyse these events in the turbulent time series. Symmetric wavelets are coherent at the edge of the transition and thus effectively define the start of a change in conditions (Hagelberg & Gamage 1994). In order to ascertain the statistical significance of the results, the wavelet coefficients are compared to a theoretical red noise spectrum calculated from the auto-correlation of the time series using the technique proposed by Torrence and Compo (1998).

The scalogram shown in Figure 1b demonstrates that wavelet analysis effectively identifies the presence and temporal location of significant structures within a time series. White indicates a high degree of correlation between the wavelet and the time series. The 'cone of influence' (area below which data are considered unreliable) is also marked.

The wavelet coefficients that are statistically significant are circled in black. Due to the high temporal resolution of the scalogram the circles appear as black lines at small scales. The data for different time series consistently show intermittent periods of significant activity at turbulent scales (< 8 s) that correspond well with bursts of CO_2.

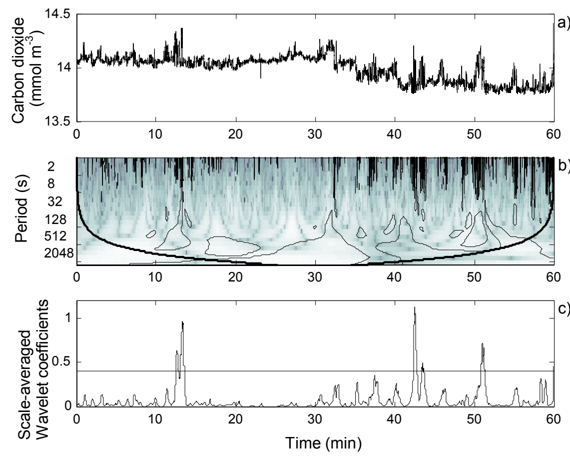

Figure 1. a) CO_2 time series, b) scalogram and c) scale-averaged wavelet coefficients (and significance level) for scales < 8 s for 2300 – 0000 (LST) June 26th 2001.

The mean modulus of the wavelet coefficients at scales < 8 s (the scales at which the largest proportion of significant structures can be found) was then calculated. Three significant events are identified in Figure 1c. Averaging over this range of scales limits the effect of instrumental noise or shear-generated turbulence, which due to the low wind speeds, is expected to be limited to very small scales (~2 s). This process was repeated for the temperature (T) time series to ascertain the relationship between the two scalar variables at these scales.

3. RESULTS AND DISCUSSION

The technique developed above was applied to 30-minute CO_2 and temperature time series recorded during a period of anti-cyclonic conditions observed between 2100 - 0700 June 23rd – 27th 2001. The mean wind speed in this period was typically < 2 m s^{-1} and the friction velocity was < 0.3 m s^{-1}. On all four nights the prevailing wind flow was initially NW followed by a marked shift to SE at 0230, that suggests the development of a local wind regime. Sunset occurs at approximately 2100 and sunrise at 0600. The sensible heat flux remained positive throughout each of the four nights. Under these conditions shear turbulence is expected to be minimal across the top of the urban canopy layer (UCL) providing good conditions to identify the penetration of convective plumes from the UCL into the UBL.

Corresponding author address: J.A. Salmond, Dept. of Geography, 1984 West Mall, Vancouver, B.C. V6T 1Z2; e-mail: jsalmond@geog.ubc.ca

During the course of the four nights 181 significant 'spikes' in CO_2 concentration are observed, with a mean duration of 81 s, i.e. with a mean spacing of about 12 min. No relationship between the number or duration of CO_2 'spikes' and wind speed or direction could be identified for this time period. This supports the hypothesis that these events are primarily thermally driven.

The maximum number of CO_2 spikes in the time series occurs at 0000 (Figure 2). At this time a marked temperature difference is anticipated between the UBL and UCL as strong radiative cooling of (clay tile) roof tops cools the base of the UBL, whilst the reduced sky view, and greater thermal inertia of surface materials in the canyons limits cooling of the UCL.

Figure 2 illustrates strong positive correlation between the T and CO_2 time series at scales of <8 s between 2300 – 0200. This is to be compared to a mean correlation coefficient of -0.4 for the two time series at all scales throughout the time period. Given that both warmer temperatures and higher CO_2 concentrations can be expected in the UCL, this suggests that at turbulent scales the observed spikes in CO_2 concentration are generated by the injection of convective plumes from the UCL into the UBL.

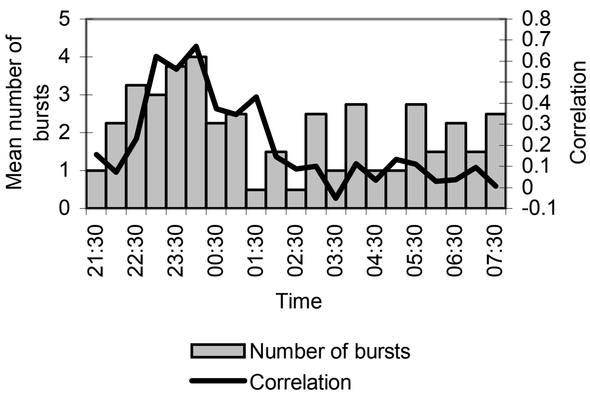

Figure 2. Mean number of 'bursts' identified and the correlation between temperature and CO_2 time series at scales < 8 s, between 2130 – 0730 (LST) on 23/06/01 – 27/06/01 (Note: Mean of 4 days data).

Few 'spikes' in CO_2 concentration are observed between 0130 and 0230. At this time changes to the wind regime may result in increased turbulence thereby masking evidence of coherent plumes from the UCL. However, although a coincident increase in the mean temperature of the UBL is observed, there is no evidence of increases in sensible heat flux or u_*. Thus the combination of increased CO_2 concentrations in the SE air flow (Figure 3) and absence of traffic may reduce the CO_2 gradient between the UCL and UBL limiting the number of plumes detected.

Although an increased number of 'spikes' can be identified from 0300 onwards Figure 3 illustrates that the concentration of CO_2 in each 'spike' is now less than the mean concentration of the time series, representing a negative spike in concentration. The mean correlation between temperature and carbon dioxide at turbulent scales is also much weaker (Figure 2).

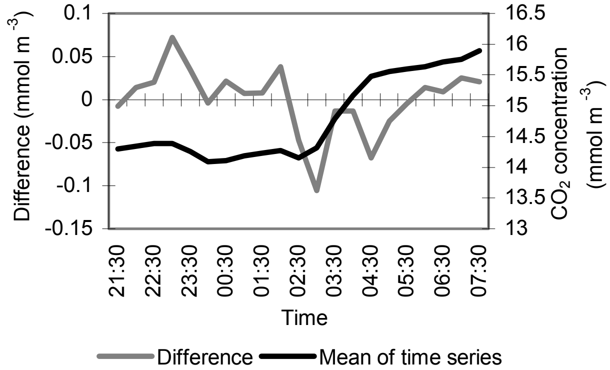

Figure 3. Mean CO_2 concentration and difference between CO_2 concentration in bursts and time series mean for 2130 – 0730 (LST) on 23/06/01 – 27/06/01.

4. CONCLUSIONS

Significant bursts in CO_2 concentration are seen throughout nocturnal time series at a densely built site in Marseille. They are most pronounced during the late evening hours when there is strong correlation between the atmospheric structures observed in the temperature and CO_2 time series at turbulent scales. Evidence suggests that these bursts, observed above roof-level, are related to intermittent venting of sensible heat from the warmer urban canopy layer. However, later in the night, the reduced gradient in CO_2 concentrations with height, perhaps due to local advection in the UBL and/or reduced traffic emissions in the UCL, limits the value of CO_2 as a tracer of convective plumes in the UBL.

5. ACKNOWLEDGEMENTS

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