TRANSPORT OF HEAT, WATER VAPOR AND CARBON DIOXIDE BY LONG-PERIOD EDDIES IN THE STABLE BOUNDARY LAYER

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Abstract

The vertical transport of heat and trace chemicals for a night in April has been studied with a wavelet analysis and conventional one-hour averages. It was found that for the night of April 20, 2009 turbulent kinetic energy, heat and trace chemicals were transported directed downward from the jet core. The most significant periods for this transport were less than 5 minutes and greater than one hour with intermittent transport taking place in the 5 min to 1 hour time frame.

Introduction

The nocturnal boundary layer is characterized by turbulent intermittency, long period oscillations, and a slow approach to equilibrium, (Mahrt, 1999). Although turbulence is usually maintained by surface friction, downward transport from low-level jets can also play an important role in turbulence maintenance and in the transport of scalars, Mahrt (1999), Banta et al. (2006).

The eddy covariance flux measurement technique assumes continuous turbulence which is unusual in the stable boundary because significant transport occurs via turbulent eddies whose periods are long compared with the averaging time (Goulden et al., 1996). Systematic error in eddy flux measurements is attributed mainly to the neglect of long period eddies.

Banta et al. (2006) noted that observations of turbulence below the low level jet suggested that while upward transport of turbulence kinetic energy (TKE) is common, downward transport from the jet can also occur. They found that in the CASES 99 experiments that turbulence scaled well with the strength of the low-level jet, and that surface cooling was more important than surface roughness

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because nocturnal turbulence is intermittent and non-stationary, the appropriate averaging time for calculation of TKE and EC fluxes is not obvious. Wavelet analysis is, thus, a more suitable analysis tool than conventional Fourier analysis.

Data

Data for this study were collected from a 300 m tower in a patchwork landscape of pine/deciduous forest, residential, and pasture in moderately complex terrain. Sonic anemometers and LI-COR water vapor/carbon dioxide open-path analyzers were located at 30, 61 and 300 m. Wind measurements to altitudes of 600 m were obtained from a Doppler sodar ~22 km to the east of the tower. The sodar was used to characterize the mean wind behavior and to position the tower levels with respect to the jet maxima. Nights with well-defined jets were selected. Jets with northeast winds, shaded by the tower, were excluded.

One night selected for study is April 19/20, 2009. A 5-day plot of sodar data for this night is shown in Fig. 1. The jet core was centered at 450 AGL with a maximum of 20 m/s. The sodar data indicate that the jet extended downward to ~30 level. Although the sodar and WJBF TV tower were separated by ~22 km, good agreement can be seen in the 300 m wind speeds, as shown in Fig. 2. This implies that the sodar winds can be used to position the WJBF levels within the jet.

Fig. 3 shows the triple correlation of the vertical eddy flux for the three levels. The negative values at 30 and 60m indicate downward transport of TKE (Banta et al. (2006), while the 304m transport is near zero or slightly positive. This is consistent with Fig. 1 which shows the 300m level to be near the jet core.

Fig. 4 is a wavelet analysis of the vertical velocity for an 8-hour period beginning at 20:00 EDT on April 19, 2009. The figure shows almost

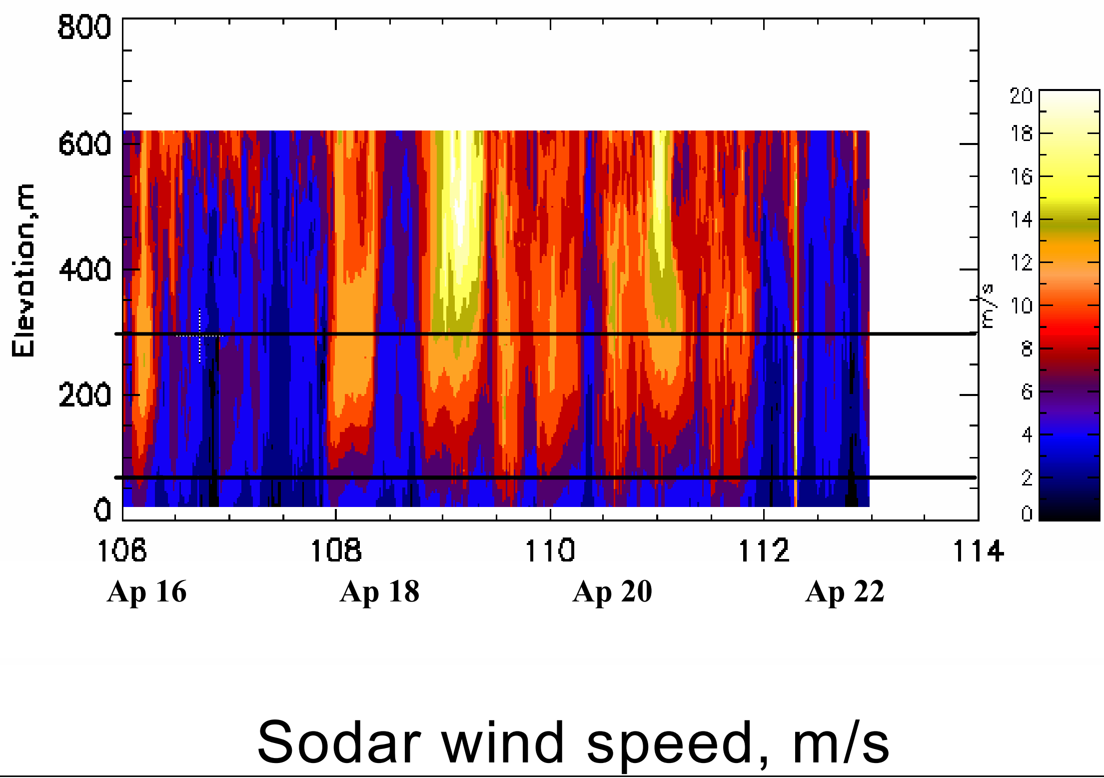

Fig. 1 Sodar wind speed, Ap 16 – Ap 18

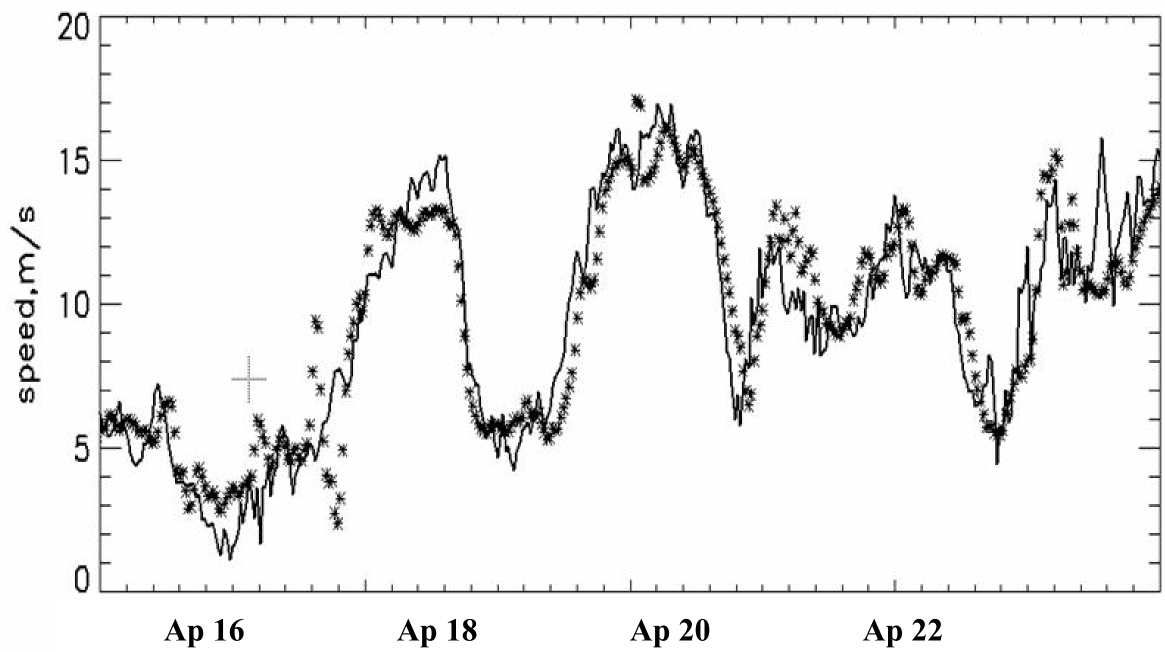

Fig. 2: Wind speed, at 305m on the tall tower, solid line,and sodar, asterisks. For Ap 16-22

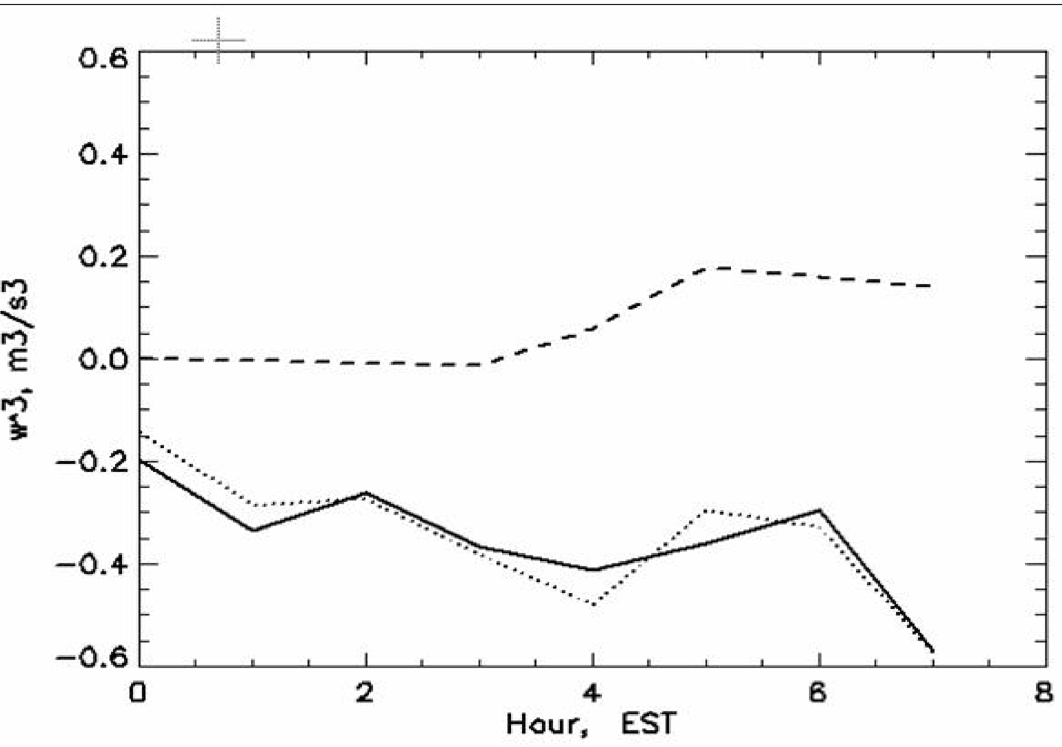

Fig. 3: Vertical velocity $(w')^3$ fpr the 30, (solid). 60, (dotted) and 304m (dashed) elevations.

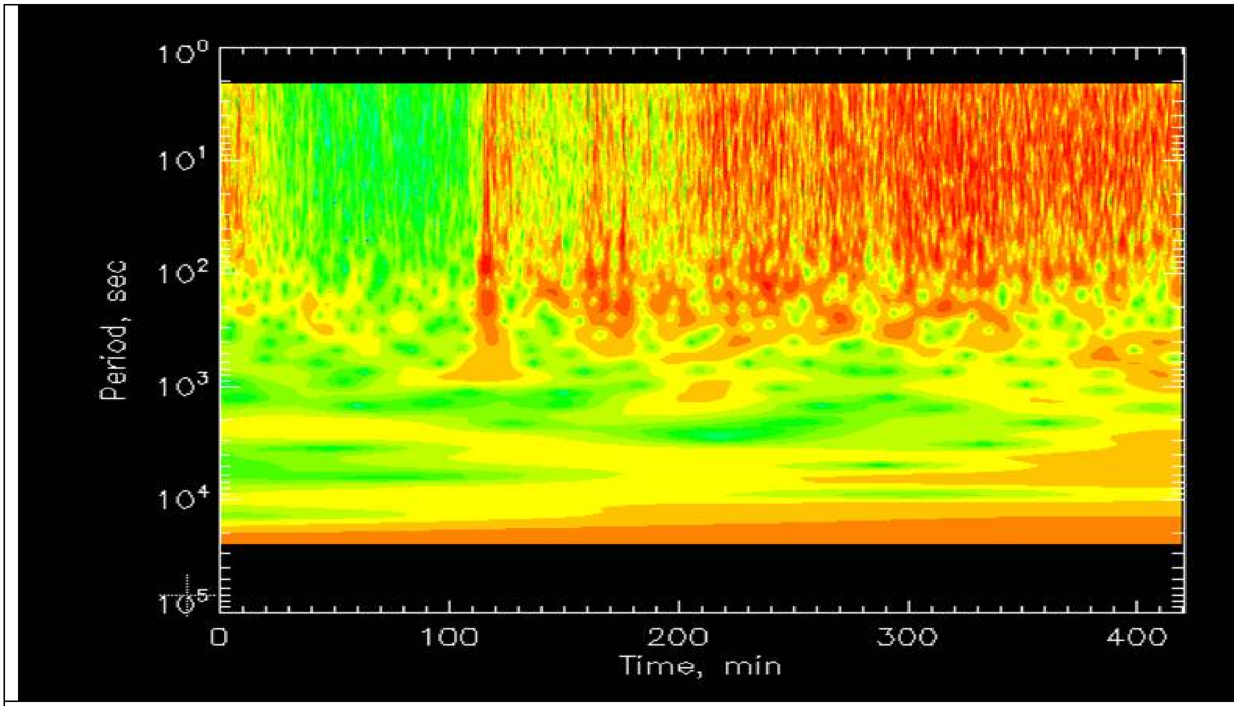

Fig. 4: Log vertical velocity spectrum and 304m

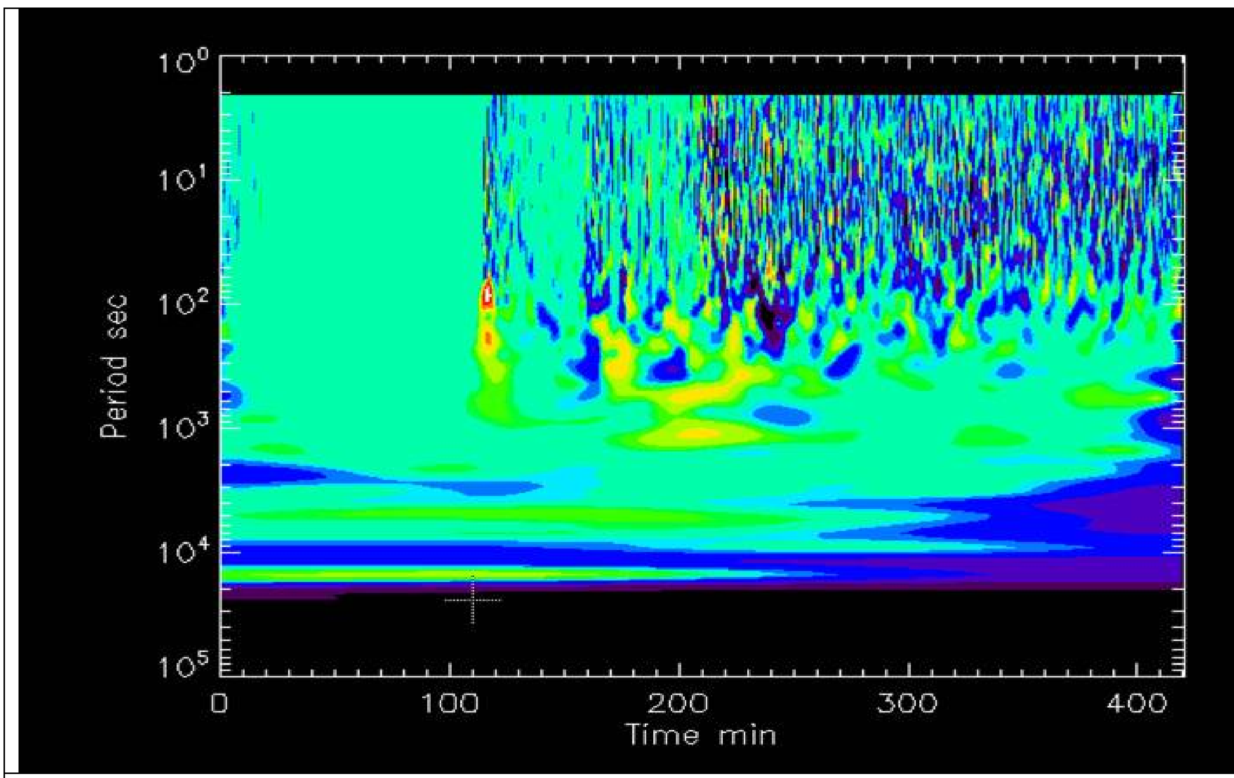

Fig. 5: Vertical velocity/temperatue co-spectrum at 304m.

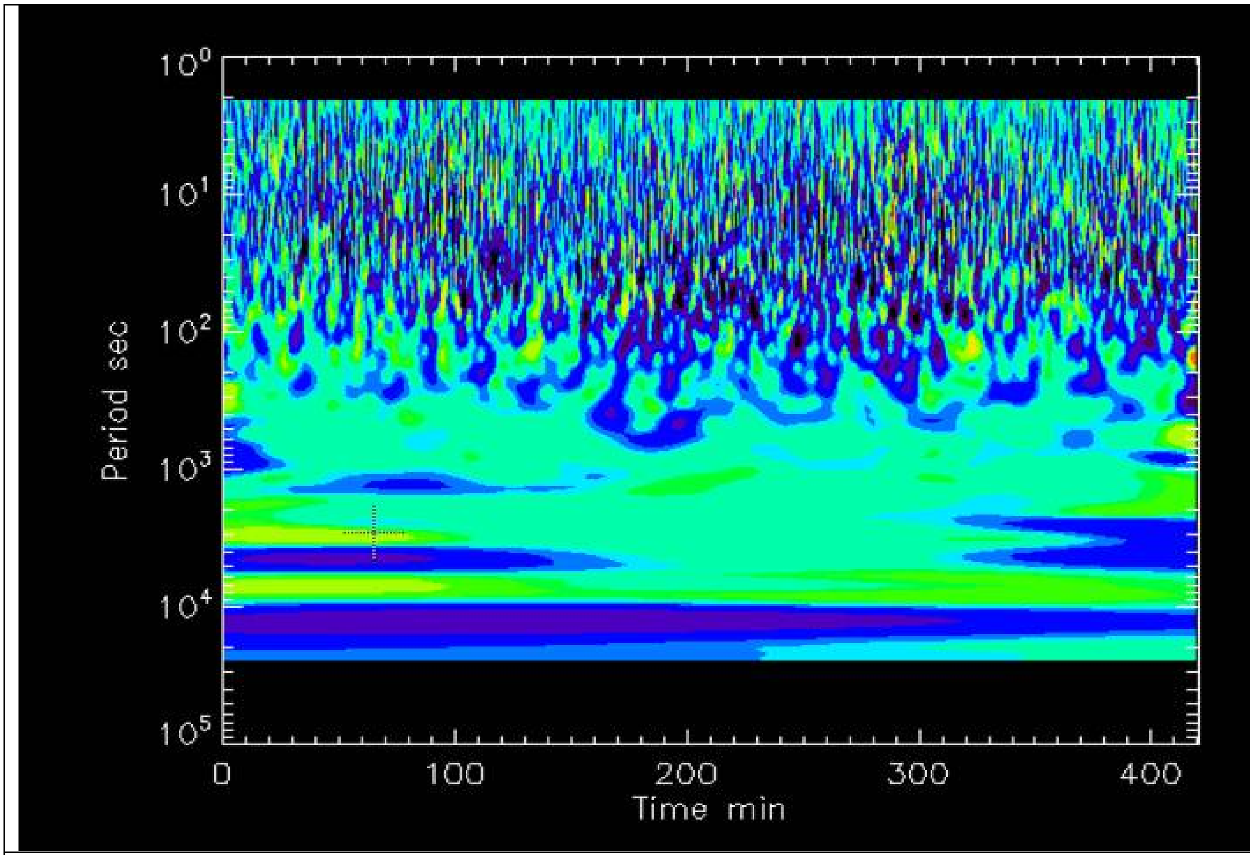

Fig. 6: As in Fig. 5 but for 60m

Fig. 5 shows a wavelet analysis for (w'T') for the same period. The general pattern is comparable to that of the vertical velocity, as expected.

Fig. 6 shows the heat flux at 60m for the same period. The turbulence is continuous and most of the transport occurs with waves with periods less than 10 minutes.

Discussion and Conclusions

The analysis of eddy fluxes of heat, water vapor and carbon dioxide has shown that significant nighttime transport occurs by eddies with periods of less than 5 minutes and greater than one hour, and intermittently for periods in between these periods. This suggests that the usual practice of averaging over one hour or less may under predict the actual transport. Longer period analysis is recommended for more accurate flux calculations.

References

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