Surface Boundary Layer of Non-homogeneous, Fetch-limited Surfaces: Implications for Flux Measurement

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INTRODUCTION

Micrometeorological techniques are a useful tool for making surface flux measurements because they provide near continuous, direct measurements without disturbing the surface. However, the underlying theory behind these techniques typically requires a large, homogenous study area (i.e., adequate fetch). In many circumstances where flux measurements are needed, these requirements can only marginally be met, making it important to have an effective means for excluding sampling periods when the instruments are sampling outside the study area or when turbulent conditions are not well developed.

Hammerle et al. (2007) concluded that with appropriate quality control, eddy covariance (EC) measurements could be made over complex terrain (mountain meadow on a steep slope) with similar quality of that obtained over flat terrain. The basis of their quality control methods included stationarity and integral turbulence filters (Foken and Wichura, 1996), and a footprint filter using the model of Hsieh et al. (2000), all applied during post-processing. This research will show how Hammerle's integral turbulence and footprint tests can be used to make real-time sampling decisions for other micrometeorological techniques (i.e., relaxed eddy accumulation, gradient), where filtering after the fact isn't possible.

OBJECTIVE

Show how the integral turbulence test and footprint tests can be used to exclude periods with poorly developed turbulence or inadequate fetch using EC measurements from a commercial cattle feedlot.

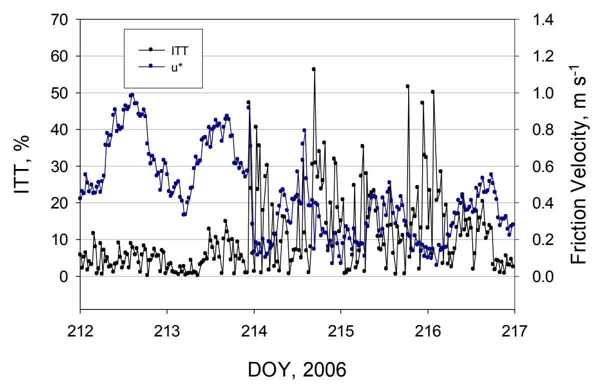
METHODS

Location: Commercial cattle feedlot in central Kansas.

Instrumentation: Eddy covariance data (i.e., time series of wind speed (3D), air temperature, CO_2, and water vapor) were collected at 20 Hz using a sonic anemometer (CSAT-3, Campbell Scientific, Logan, UT) and open-path infrared gas analyzer (IRGA, LI-7500, Li-Cor, Lincoln, NE) positioned 6 m above the surface.

Figure 1. Map of the 30,000-head cattle feedlot and a photograph of the flux tower positioned at the northern edge of the operation. Fetch to the south, the prevailing wind direction, was 1600 m.

INTEGRAL TURBULENCE TEST



Eddy covariance and other micrometeorological techniques require sufficient turbulence to insure surface layer similarity. Traditionally, a minimum friction velocity has been used to filter out periods of weak turbulence. However, the integrated turbulence test (ITT), which is a function of measurement height, Monin-Obukhov length, friction velocity, and the standard deviation of vertical wind speed; has proven to be a much better filtering approach (Hammerle et al., eqs. 1 and 2). If the ITT test statistic is less than 30 % then well developed turbulence can be assumed.

FOOTPRINT TEST

Footprint modeling showed that, on average, the tower strongly sampled the first few pens immediately south of the tower (Fig. 2). However, the edges of the footprint could easily extend beyond the edge of the feedlot when wind directions shifted to the southeast/southwest or during stable conditions. Since a footprint model is an approximation, a method was needed to experimentally determine the actual edge of the sampling source area.

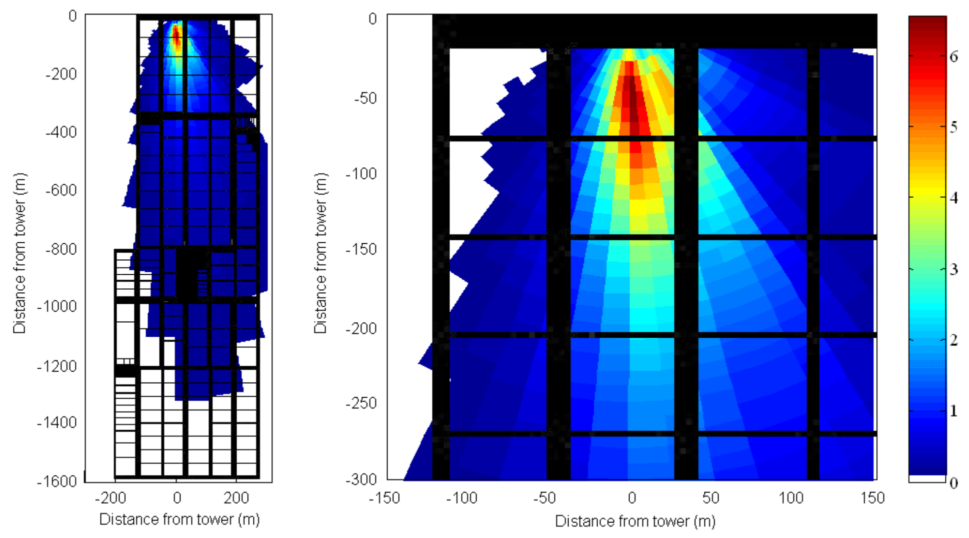


Figure 2. Contour plots of the source area footprint when wind direction was southerly.

Respiration from the cattle in the feedlot provides a near constant flux of CO_2, presenting a unique opportunity to evaluate the sampling footprint. A composite CO_2 flux curve has a diurnal cycle between 3 and 5.8 mg m^{-2} s^{-1} (Fig. 3). The CO_2 fluxes from the surrounding crop fields never exceed 0.6 mg m^{-2} s^{-1}. Thus, a comparison of the measured CO_2 flux with the expected flux from the pens makes it easy to discern when the EC tower is sampling outside the feedlot (Fig. 4).

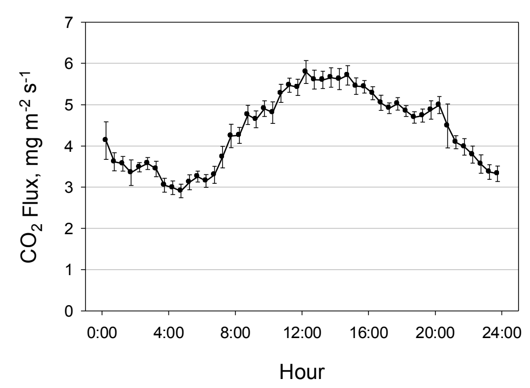


Figure 3. Composite graph of the diurnal CO_2 emissions from the feedlot. Data were filtered to only include periods when the winds were from the south and the source area was centered over the pens (Fig. 3).

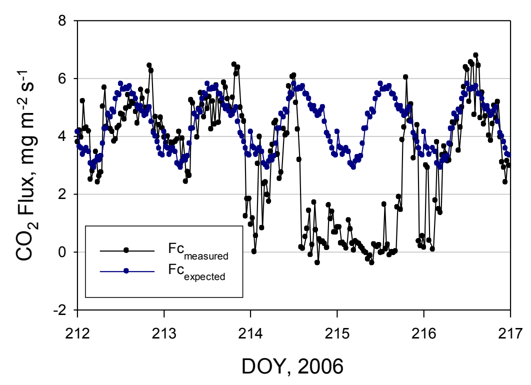


Figure 4. Example of measured CO_2 fluxes at the tower to the expected CO_2 flux from the cattle pens during a 5-day period. Deviations between the measured and expected flux indicate the tower was sampling outside the feedlot.

The Hsieh model can be used to predict the fraction of the measured flux originating a certain distance from the tower. Hammerle excluded data if x90, the fetch that accounted for 90% of the flux, extended beyond the boundary of the study area. We were able to calibrate our data screening procedure by computing the RMSE between the expected and measured CO_2 fluxes at the feedlot (Fig. 4) after applying different filtering criteria (x50, x60 … x90). Results showed that data should only be excluded when the Hsieh-model value of x70 extended beyond the boundaries of the feedlot (Fig. 5a). Using this criteria, the footprint filter retained 58% of the data and filtered out 42% (Fig. 5b).

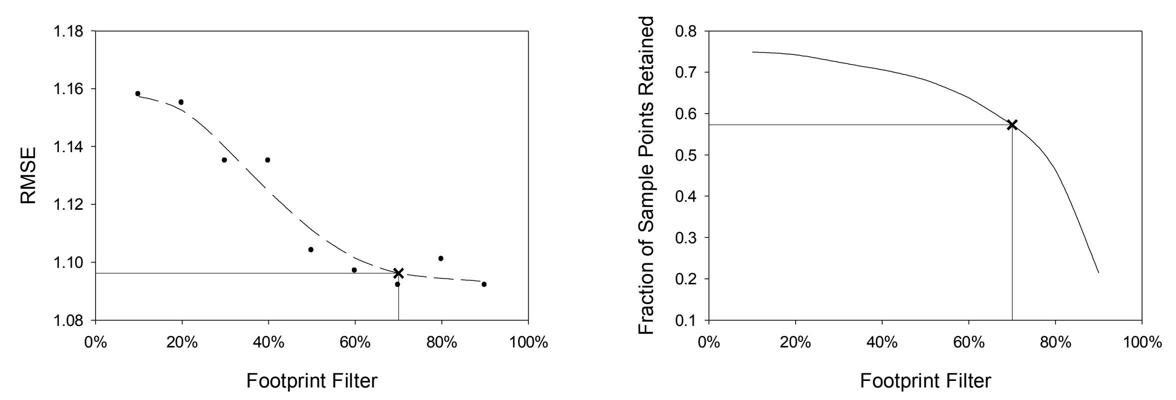


Figure 5. (a) Root mean square error between the expected and measured CO_2 fluxes as a function of the footprint filter criteria. (b) Fraction of the sample points retained at different filtering levels. An x-axis value of 70 represents a filter where flux data would be retained (i.e., considered valid) if the Hsieh model predicted 70% or more of the flux originated within the boundaries of the feedlot.

RESULTS: Combining Tests

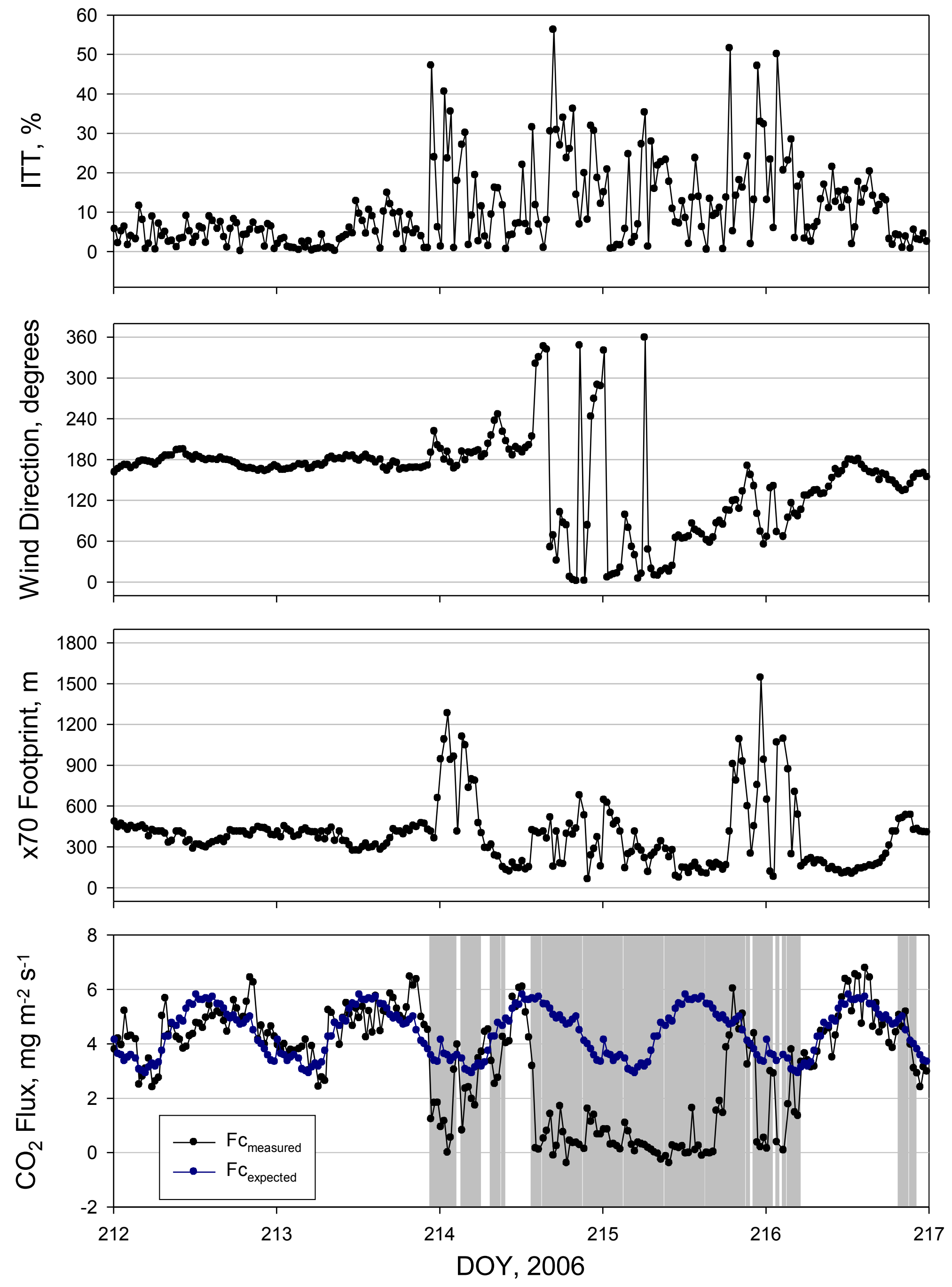


Figure 6. (a) integral turbulence test, (b) wind direction, (c) x70 footprint calculations, and (d) measured CO_2 flux versus expected CO_2 fluxes, with the gray areas representing periods where test(s) failed and sampling ceased.

CONCLUSIONS

- The integral turbulence test (ITT) was effective at eliminating periods with apparently poor turbulence and was able to retain more data than more traditional filters (i.e., friction velocity minimum).
- The Hsieh-modeled x70 footprint test appeared to be the most effective value for excluding periods where the fetch extended beyond the feedlot boundaries without being too aggressive in eliminating sampling periods (around 40% of sampling time excluded).
- The combination of the ITT and footprint tests appears to be effective at eliminating undesirable sampling periods at sites with limited fetch (Fig. 6). This approach can be programmed into the same dataloggers used to operate EC instruments in the field. Thus, these tests could be used to control real-time sampling processes such as starting and stopping a relaxed eddy accumulation system that captures up- and down-moving eddies in denuders (Ham and Baum, 2007).

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