Eddy Covariance Measurements of Gas Emissions in a Beef Cattle Feedlot

Prajaya Prajapati and Eduardo Alvarez Santos

Department of Agronomy, Kansas State University

Introduction

Global greenhouse gas emissions (GHG) from ruminants contribute about 18% of the total anthropogenic emissions. Accurate emission measurements from confined animal feeding operations (CAFO) are required to reduce uncertainty in the GHG budget and to evaluate mitigation strategies.

Micrometeorological methods can be an alternative to measure gas emissions from CAFO's. The eddy covariance (EC) technique is a micrometeorological method that allows precise, direct, non-intrusive and near-continuous flux measurements over large areas. However, the unique surface and boundary layer characteristics of cattle feedlots, especially surface heterogeneity, impose some measurement challenges. Additionally, spatial variation in emission due to animal position changes, wind direction and atmospheric stability variability can cause variation in source strengths. Consideration of these factors is necessary for accurate estimation of flux and overall GHG budget.

Objectives

- to assess the performance of a closed-path analyzer to measure CH_4, CO_2, latent and sensible heat fluxes in a beef cattle feedlot;
- to investigate the spatial variability of eddy covariance fluxes measured above the surface of a beef cattle feedlot using an analytical flux footprint analysis.

Methods

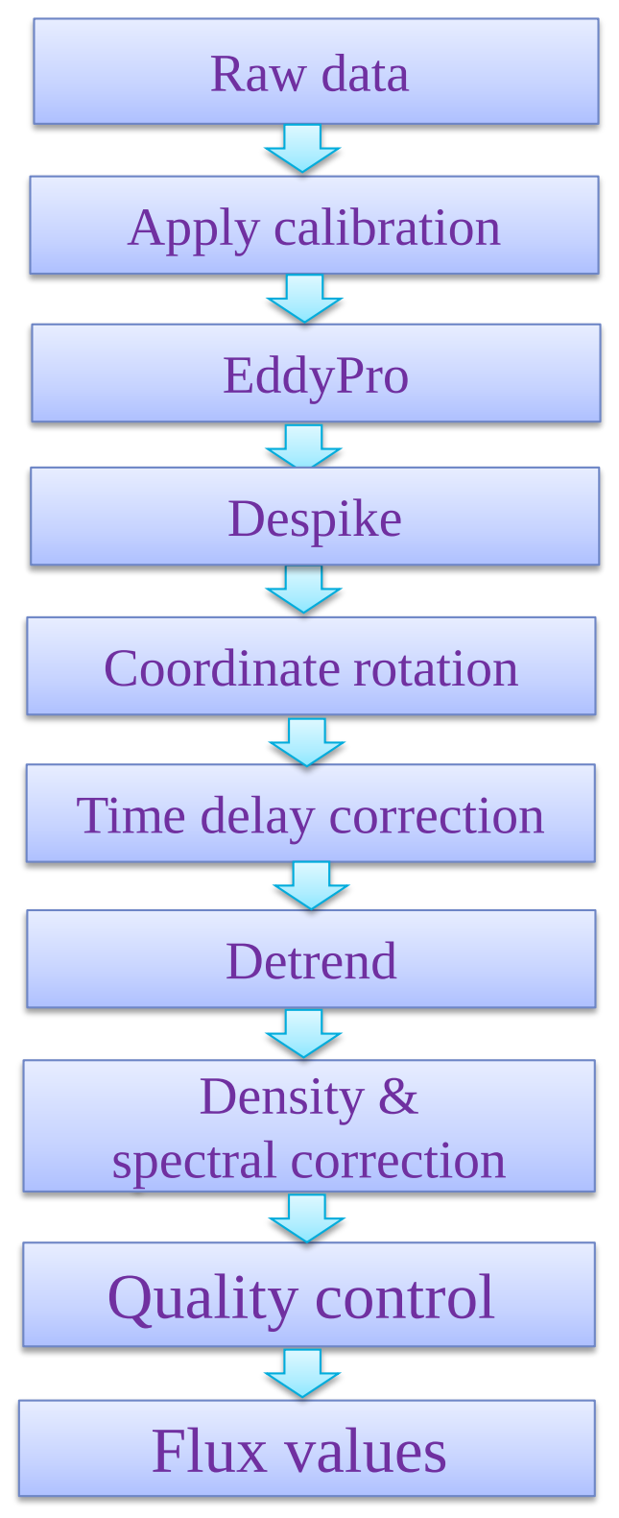
Location: Commercial cattle feedlot in western Kansas.

Instrumentation: Data were collected from August, 2013 to May, 2014. Concentrations of CO_2 and CH_4 gases were measured by open-path (LI-7500A, LI-COR Biosciences) and closed path gas analyzer (G2311-f, Picarro Inc., USA) respectively. Wind vectors and Temperature were measured with 3D sonic anemometer (CSAT3, Campbell Sci., Inc., USA)

Figure 1. Photographs of the flux tower positioned at the northern edge (left), and animals inside the pens of the feedlot (right).

Flux Calculations

High frequency raw data files were converted into 30-min files and calibrations were applied to the concentration data using Matlab (ver. 8.4, The mathworks, Inc., Natick, MA). Half-hour files were processed with Eddy pro software package (version 5.2, Licor- Biosciences).



Raw data

Apply calibration

EddyPro

Despike

Coordinate rotation

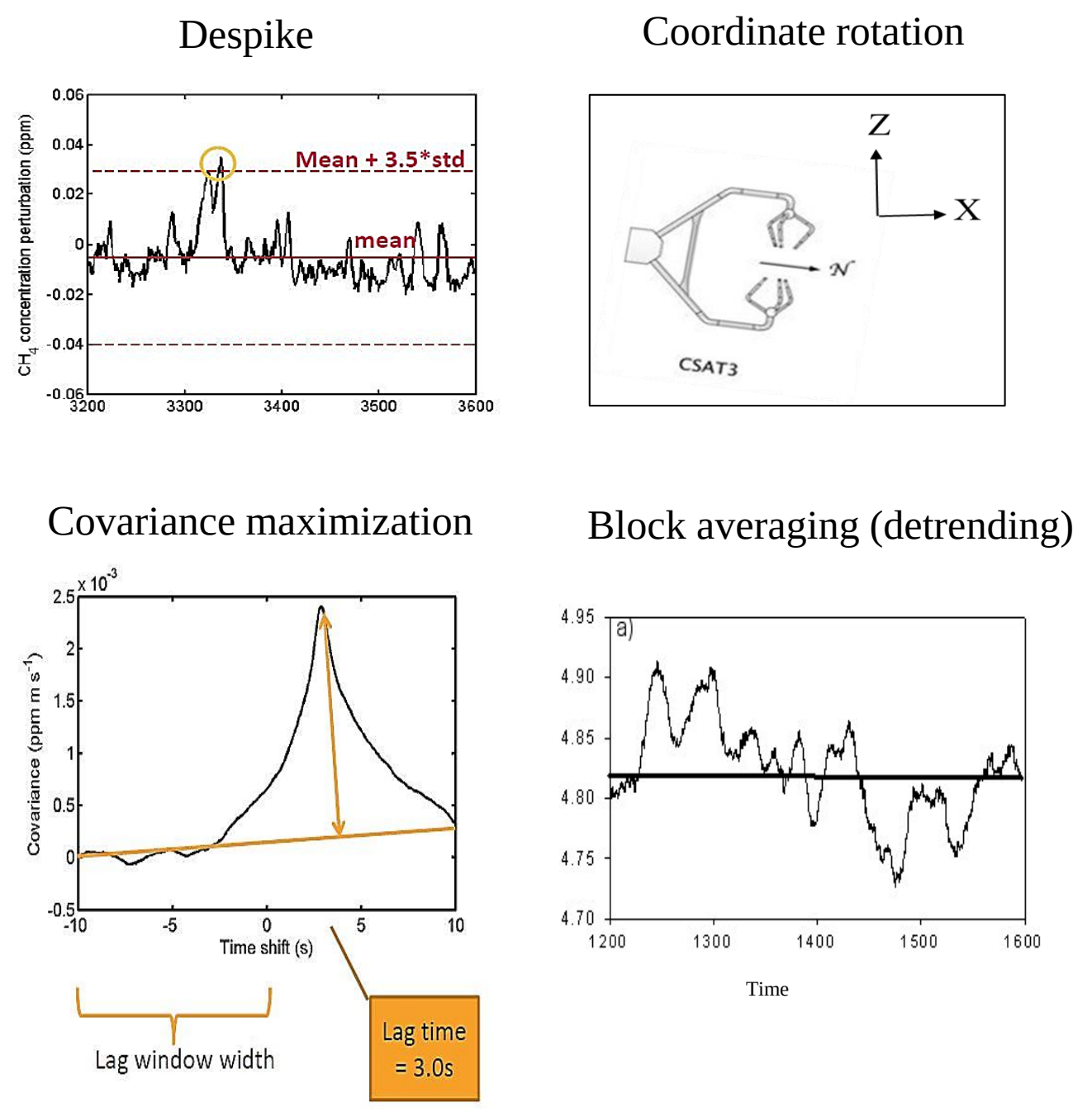
Time delay correction

Detrend

Density & spectral correction

Quality control

Flux values



Despike

Coordinate rotation

Covariance maximization

Block averaging (detrending)

Source: https://www.atm.helsinki.fi/EddyUHcourse_2015.php

Results

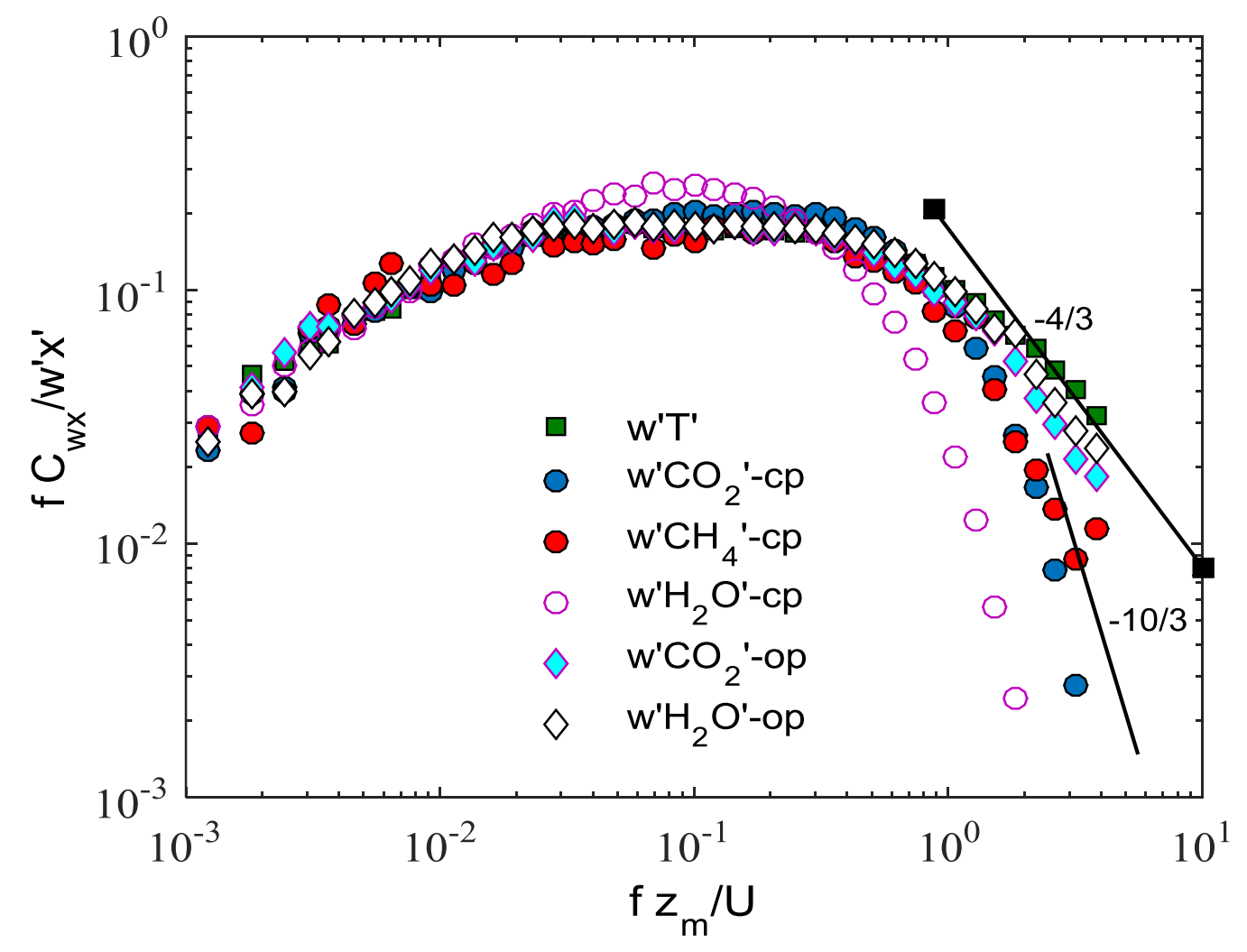


Figure 2. Normalized frequency (*f z_m/U*) and averaged normalized co-spectra (*fC_{wx}/w'x'*) for: sonic anemometer temperature (*w'T'*), carbon dioxide (*w'CO_2'*), methane (*w'CH_4'*) and water vapor (*w'H_2O'*). The co-spectra were calculated using half hourly periods from 12–15 (CST) for the entire study period (August 2013 – May 2014).

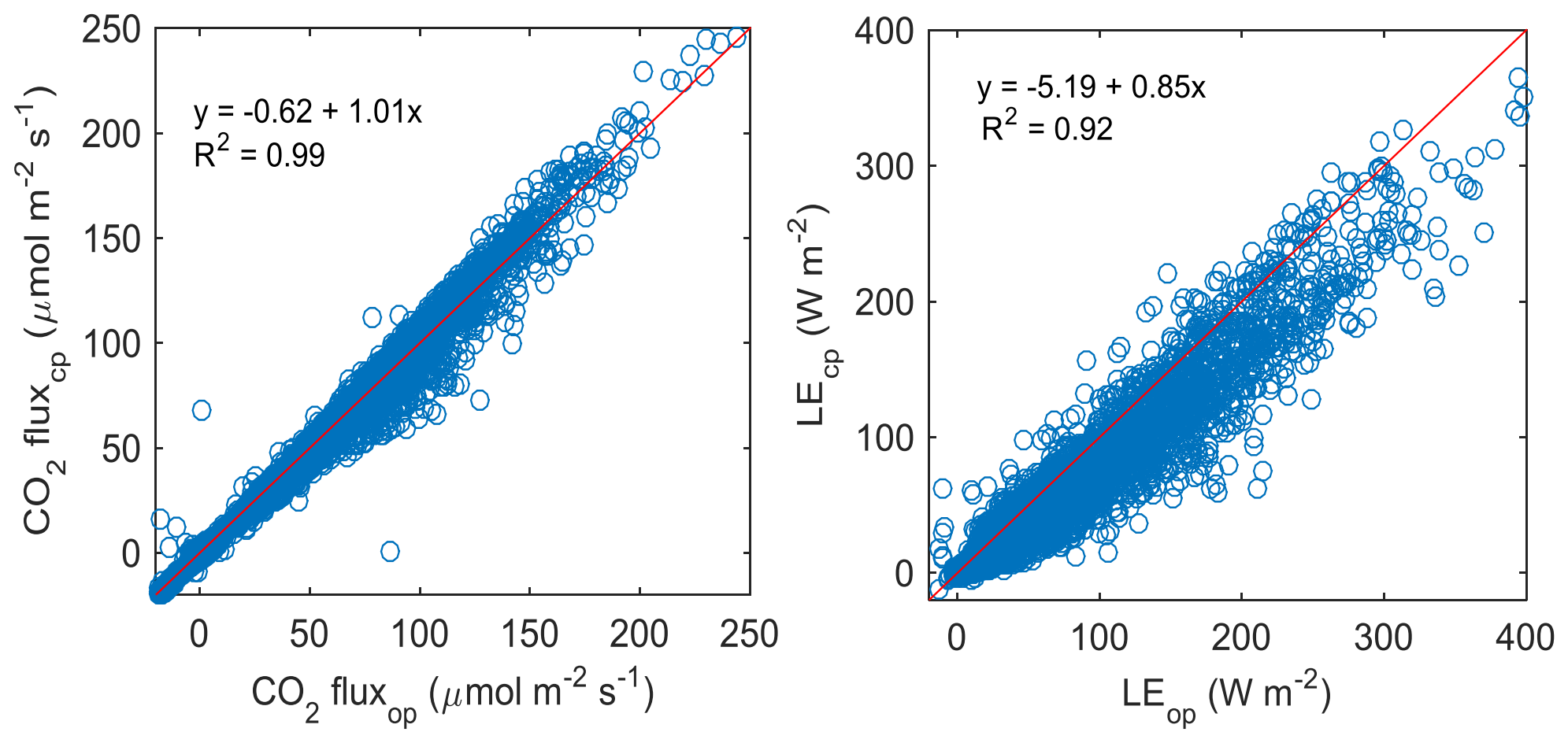


Fig. 3. Comparisons between a) CO_2 flux (left), and b) latent heat flux (right) obtained from concertation data of two gas analyzers: closed-path (cp) and open-path (op) analyzer.

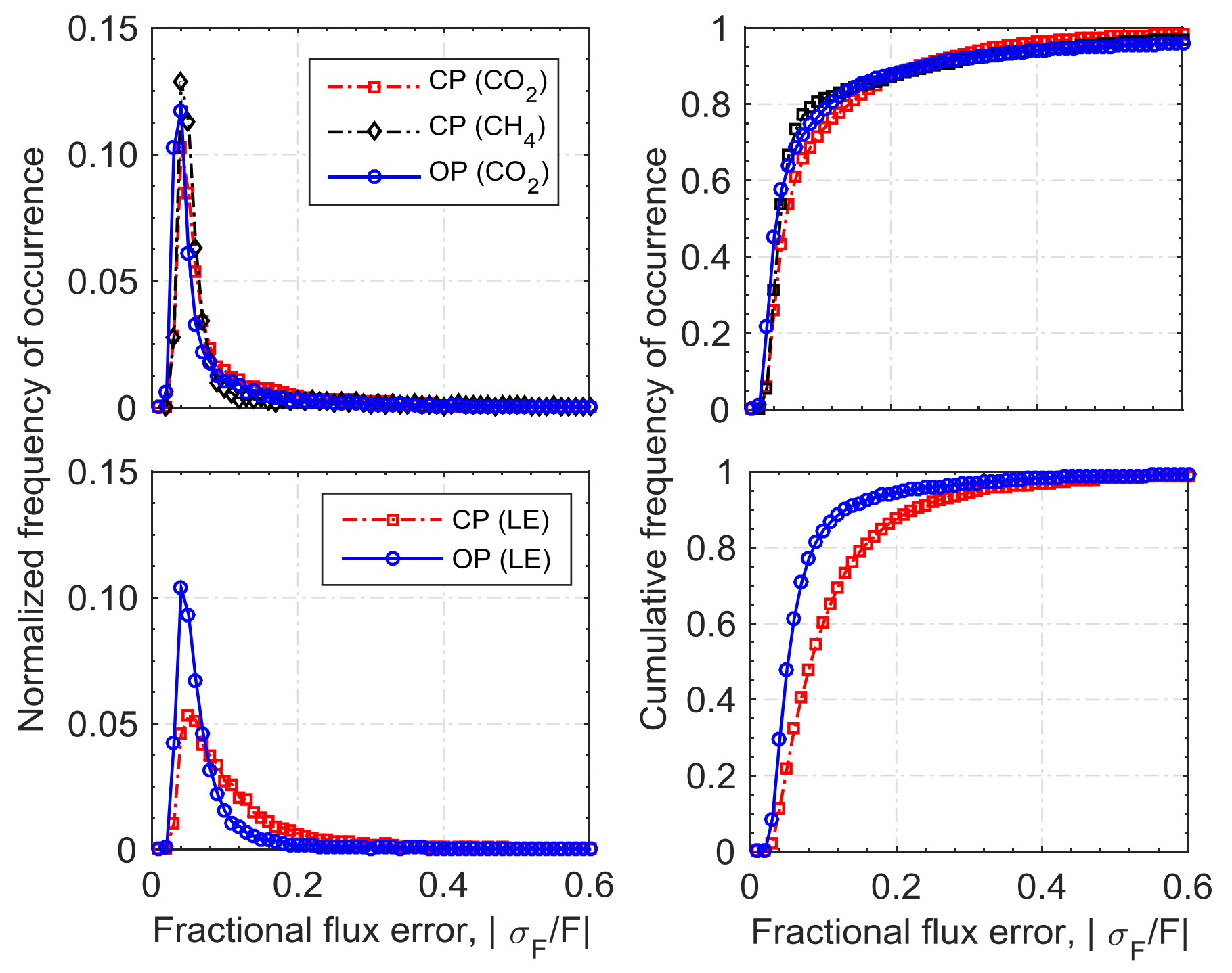


Figure 4. Distribution curves of absolute value of fractional flux error |σ_F /F| (left plot), and cumulative sums of relative frequency of occurrence of respective flux (right plot).

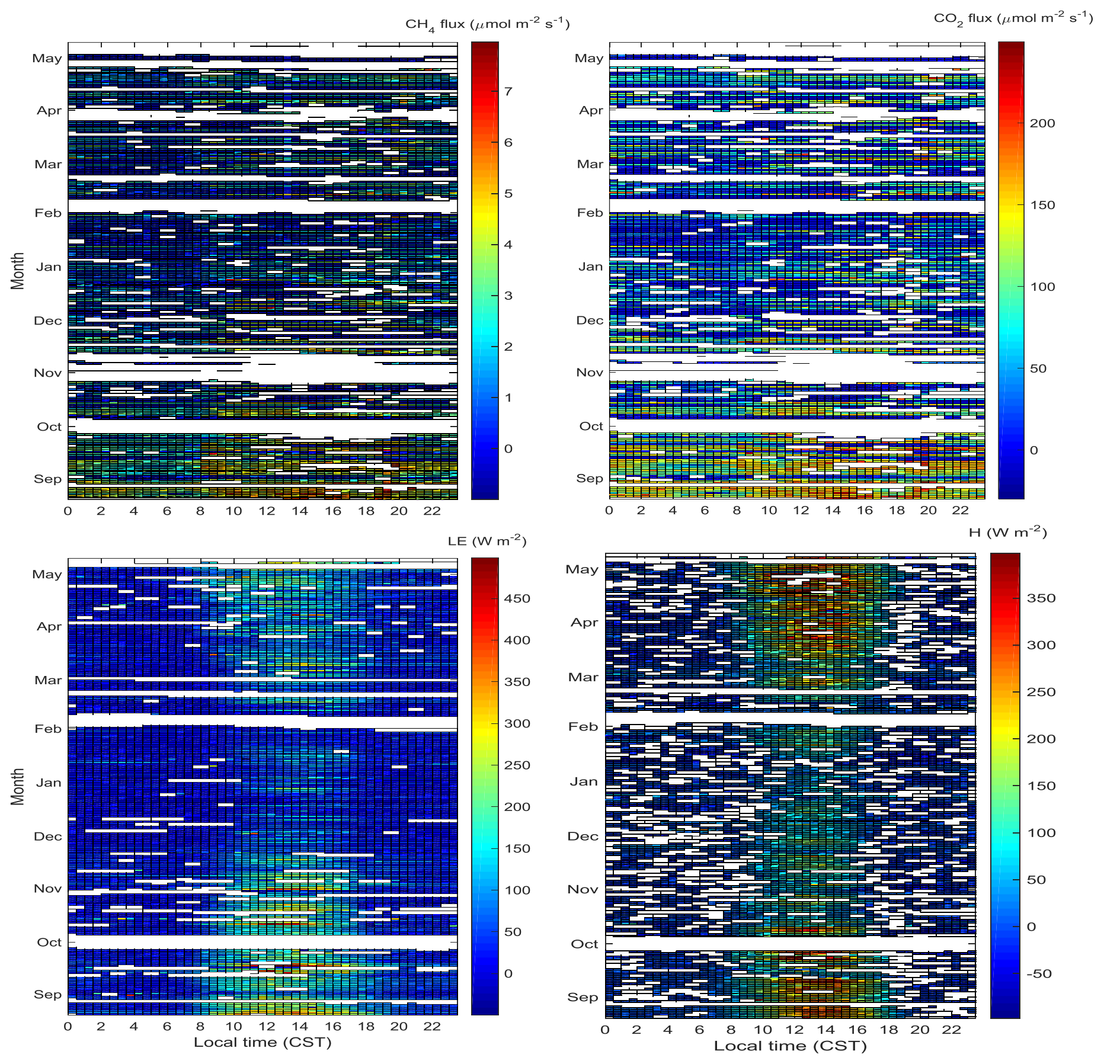


Figure 5. Temporal dynamics of: CH_4 (Top left), CO_2 (Top right), latent heat (LE) (bottom left) and sensible heat fluxes (bottom right).

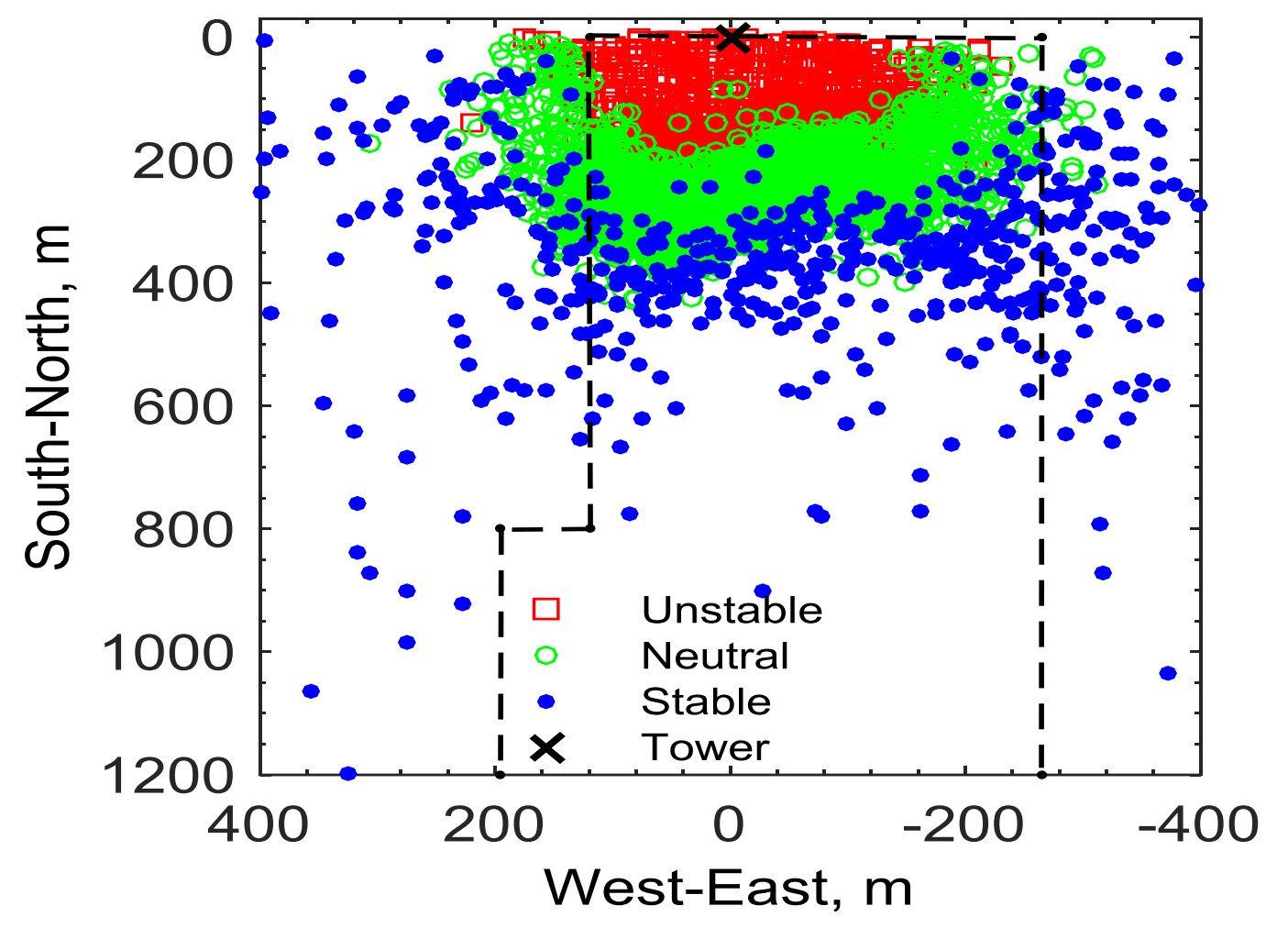


Figure 6. Relationship between the atmospheric stability conditions (near neutral: |L| > 100; unstable condition: -100 < L < 0; stable periods: 0 < L <100) and the upwind distance representing 70% of the surface flux. Only half hourly periods originating from feedlot (90º <wind direction > 270º) were used. The upwind distance is calculated using footprint model by Korman and Meixner (2001). The dotted line indicates the boundary of the feedlot. L is the Obukhov length.

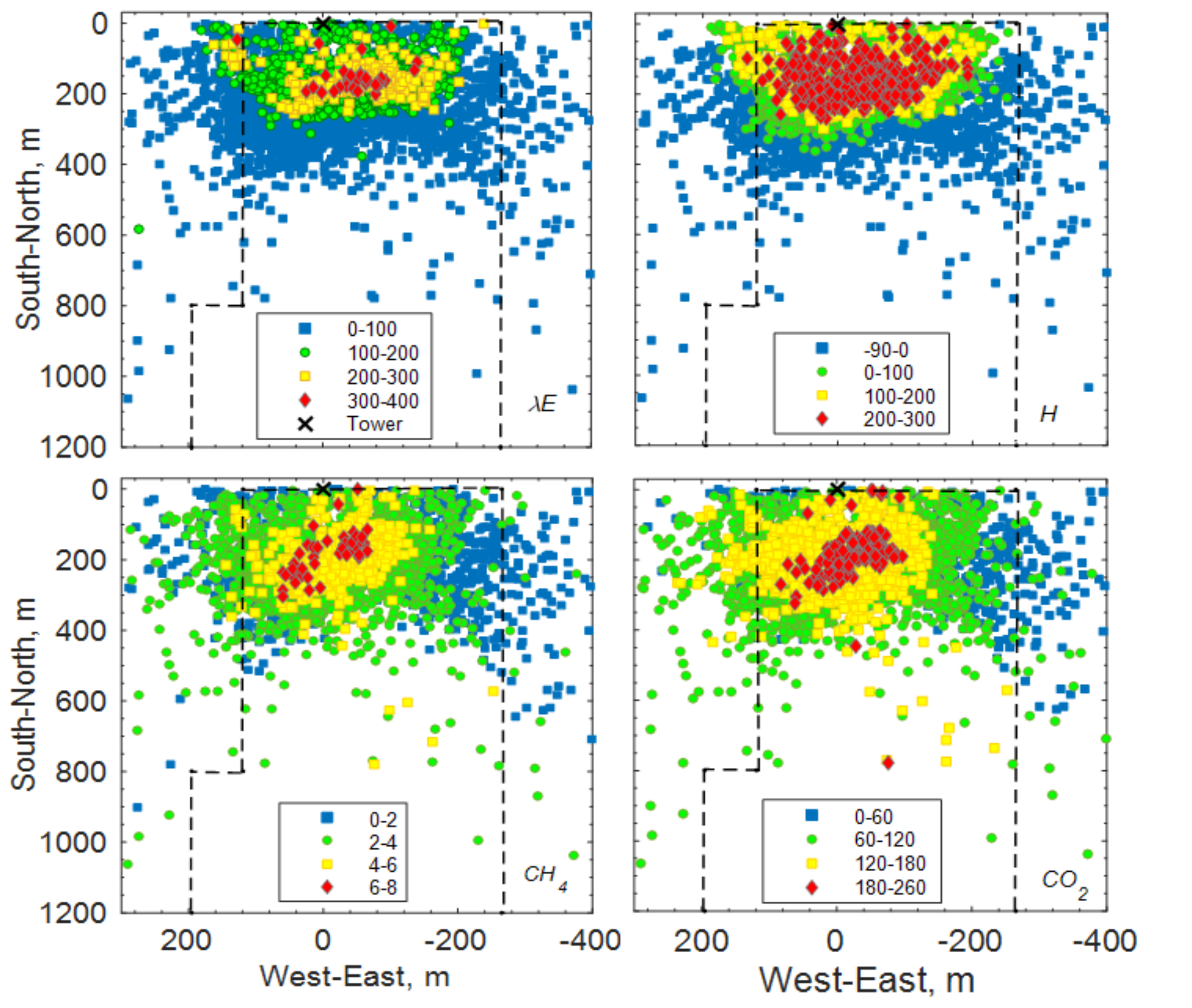


Figure 7. Spatial variability of flux densities in the feedlot. H, CH_4, CO_2 and λE denote sensible heat flux (W m^{-2}), methane flux (μmol m^{-2} s^{-1}), Carbon dioxide flux (μmol m^{-2} s^{-1}) and latent heat flux (W m^{-2}) respectively. Only half hourly data when the wind direction was from south (90-270º) and that passed the quality screening were used.

Discussion

Performance of closed-path analyzer

Co-spectra: Apart from H_2O co-spectra which showed strong signs of attenuation, gases from closed-path followed model attenuated -10/3 slope and open path followed model un-attenuated -4/3 slope. Physical adsorption and desorption of sticky gas molecules, such as water vapor, within the walls of the sampling tube and filters generally attenuate the high frequency concentration fluctuations. However, the expected shapes of co-spectral densities of CO_2 and CH_4 indicate that the closed-path analyzer performance was suitable for flux calculations.

Comparison of flux: Good agreement between CO_2 flux from CP and OP measurements (Fig. 3). The same comparison for latent heat flux indicates that the close path analyzer underestimated the latent heat flux by 15%.

Random uncertainty error: From cumulative frequency of occurrence shown on the Fig 4, it is evident that approximately 90% CP and OP values for CO_2 and CH_4 flux are between 0.20 and 0.15, respectively. Only for LE it was around 0.30. These observations further suggest good precision of the analyzer in measuring trace gas flux in a feedlot.

Flux variability

Temporal variability: The ranges of average flux of CH_4 (3 μmol m^{-2} s^{-1}) and CO_2 (110 μmol m^{-2} s^{-1}) were in agreement with the values previously reported for feedlots. Flux magnitudes were, in general, higher during the day and lower at night (Fig. 5).

Spatial variability: Larger flux densities were observed under unstable and near neutral conditions when the footprint extended over shorter distances from the tower and for south winds.
The flux density was lower when footprint extended over a larger area. Under these conditions, a larger area influencing flux measurements extended beyond the feedlot boundaries. In addition, the flux was probably biased or diluted by non-emitting surfaces (road and alleys) within the feedlot. This will be further investigated in a future study.

Conclusion

- Spectral analysis of the closed-path analyzer data and comparisons between open-path and closed-path analyzer measurements suggests that this system is suitable for eddy covariance measurements.
- We observed flux diurnal patterns, with higher flux values observed during the daytime than at nighttime.
- The atmospheric boundary layer condition had a strong influence over spatial variation in the flux densities.
- Fluxes were usually higher when the flux footprint extended over shorter distances from the tower, under unstable and neutral atmospheric condition and for southerly winds.
- Dilution from non-emitting structures (road and alleys) probably played an important role in the flux variation. Additional work will be done to confirm this hypothesis.

References

Baum, K. A., Ham, J. M., Brunsell, N. A., & Coyne, P. I. (2008). Surface boundary layer of cattle feedlots: Implications for air emissions measurement. Agricultural and forest meteorology, 148(11), 1882-1893.

Detto, M., Verfaillie, J., Anderson, F., Xu, L., & Baldocchi, D. (2011). Comparing laser-based open-and closed-path gas analyzers to measure methane fluxes using the eddy covariance method. Agricultural and Forest Meteorology,151(10), 1312-1324.

ACKNOWLEDGEMENTS

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