Using Eddy Covariance to Quantify Methane Emissions from a Dynamic Heterogeneous Area

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Extended Abstract # 310

INTRODUCTION

More than half of the world's population now lives in urban areas. The world's urban population increased from 2.3 billion in 1994 to 3.9 billion in 2014 and is projected to grow to 6.3 billion by 2050[1]. Urbanization introduces many environmental changes and challenges including an increase in waste production and consequently a demand for more landfills. Organic matter makes up about 46% of solid waste on a global scale[2]. Once the waste is dumped into landfills, part of it decomposes under anaerobic conditions and produces methane that has a global warming potential 25 times larger than CO_2[3]. In the United States, landfills are the third largest anthropogenic source of CH_4 emissions accounting for 18% of total CH_4 emissions in 2012[4]. The methane emissions can be measured using chamber-based methods, remote sensing methods such as mobile tracer correlation (TC)[5], mass balance, and eddy covariance (EC)[6] or estimated using gas production models. The application of the EC method is relatively new. The objectives of this study were to (1) measure CH_4 emission from a municipal landfill in the southern United States continuously using the EC method and periodically using the TC method and (2) to compare these two methods.

MATERIALS AND METHODS

The study was conducted at the Turkey Run Landfill, operating since 2009 in northern Meriwether County, Georgia. The landfill accepts only municipal solid waste, which includes non-hazardous household, commercial and industrial waste and construction and demolition debris. The operation and management follow the standards for municipal landfills. An EC system with an LI-7700 CH_4 gas analyzer and an LI-7500A CO_2/H_2O gas analyzer (LI-COR Biosciences, Lincoln, Nebraska, USA) was installed at 2.36 m height near the center of the landfill on April 25, 2012 and operated until May 8, 2013. Raw flux data were processed with coordinate rotation, density correction, frequency correction, and other default settings of the Express Mode of EddyPro 5.2 (LI-COR Biosciences) to obtain final fully processed CH_4 and

CO_2 fluxes. Only the flux data that met all of the following criteria were used in this study: (1). The CH_4 analyzer RSSI (Received Signal Strength Indicator) > 10. When it is raining or snowing or when dust gets into the optical path occasionally, the signal path could be partially blocked and RSSI could be below 10. This criterion ensures normal operation of the CH_4 gas analyzer. (2). The CH_4 flux footprint radius for 90% cumulative contribution < 200 m. The footprint of the methane flux mainly depends on instrument height and atmospheric stability. This filter guarantees that the CH_4 flux came from areas within the boundary of the landfill as shown in Figure 1. (3). CO_2 concentration in dry air (CO_2 mixing ratio) > 380 ppm. This eliminates abnormal readings due to bad weather or contaminations on the windows of LI-7500A CO_2/H_2O gas analyzer. (4). Friction velocity (u*) > 0.15. Low friction velocity during calm nocturnal periods could result in underestimation of fluxes because of insufficient turbulent mixing. Friction velocity was computed from wind data measured by the anemometer.

Fig. 1. A Google Earth image showing the flux footprint with a radius of 200 m at Turkey Run Landfill

The TC measurements were conducted on April 24-27, June 26-29, and December 4-6 in 2012 as well as on March 7-9, April 10-12, and May 7-8 in 2013. In each period, two acetylene tracer release points were strategically placed to maximize coverage on top of the landfill and they simultaneously released trace amounts of acetylene gas at a constant rate of about 20 LPM (21.3 g/min). Tracer correlation transect measurements were conducted at kilometer distances downwind of the landfill where the two acetylene point sources and landfill plume are well-mixed. Measurements were conducted with a mobile platform consisting of a four-wheel drive truck fitted with a 2 m tall rear bumper-mounted sampling mast that held the concentration measurement instrument G1203 (Picarro Inc., California, USA) based on cavity ring-down spectroscopy. Once a plume was located, the mobile platform transected the downwind plume while the G1203 concurrently measured concentrations of both the acetylene and methane. This transect was used to determine the landfill's methane emission rate.

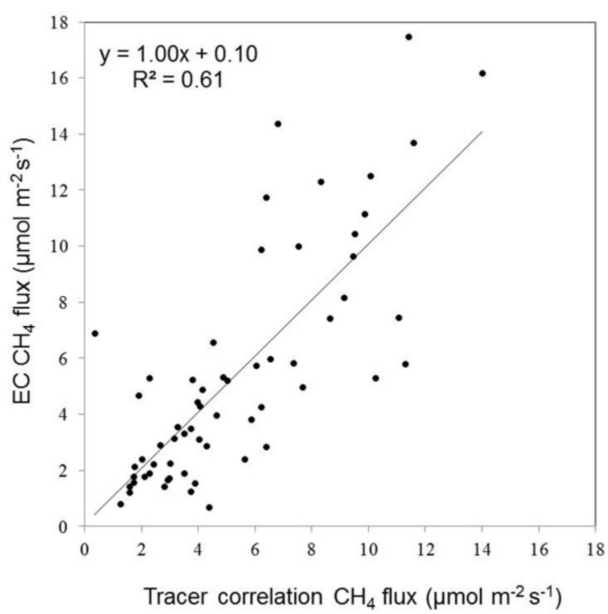
Each transect was analyzed using a program written in LabVIEW™ which allows the user to manually define the start and end time of the plume. Within the defined region, an unconstrained linear relationship was fit to the methane versus acetylene concentrations at each time point over the interval. A correlation coefficient was calculated to define the strength of the linear fit. The program also calculated the plume cross-sectional areas of both the methane and acetylene plumes. Both the slope and the ratio of the areas are used to calculate the methane emission rate where the emission rate is equal to the tracer release rate and the ratio of the molecular weights of methane and acetylene multiplied by either the slope or the area ratio. The difference in the two calculated methane emission rates is calculated and defined as the emission rate difference (ERD).

Each transect was checked for quality before accepting the methane emission rate. The transect first must pass a visual inspection, then the signal-to-noise ratio of each concentration time series must be greater than 10, the correlation coefficient of the methane and acetylene time series must exceed 80 %, and the ERD must not exceed 20%. Only transects that passed these data quality indicators were accepted for the emission rate[7]. In order to compare with the methane flux results from the EC method, the individual TC flux data were averaged in the 30 minutes prior to the time stamps and then converted from g/min for the entire landfill to µmol $m^{-2}s^{-1}$ in unit with the total area of the landfill of 192451 m^2. For example, the CH_4 flux at 10:30 am is the average during the period of 10:00 to 10:30 am. The time-delay caused by transport of CH_4 from the landfill to the TC measurement location was taken into account in the comparison.

RESULTS AND DISCUSSION

The methane fluxes measured continuously using the EC method and the correspondent flux results from the periodic measurements using the TC method are shown in Fig. 2. Overall they are consistent, although the variation in the difference between the two methods could be large on a half hour basis. The correlation coefficient between the two methods is 0.78. When all the data in Fig. 2 are averaged for each method respectively, the mean fluxes are 5.39 µmol m^{-2} s^{-1} for EC and 5.29 µmol m^{-2} s^{-1} for TC, about 2% higher with the EC method.

Fig. 2. Comparison on methane fluxes measured using eddy covariance and tracer plume methods.



In order to ensure the CH_4 measured with the EC method came from the landfill, the data are limited to a footprint with 90% cumulative contribution less than 200 m in radius. In fact, the mean radius for footprint with 90% cumulative contribution is 107 m as shown in Fig. 3, which is much less than the maximum of 200 m. This indicates that the CH_4 fluxes measured using the EC method came from the landfill. During the period of this study, wind came from all the directions with relatively more from west and less from north (Fig. 4). Methane fluxes measured with the EC method at different upwind directions are similar over the period (Fig. 5). They did not change substantially from May to October in 2012 and started to gradually increase from November 2012 until the end of the study in May 2013 (Fig. 6).

Fig. 3. Average upwind distances for different cumulative contribution to methane flux over the period of April 26, 2012 to May 8, 2013. Data are means ± standard deviations.

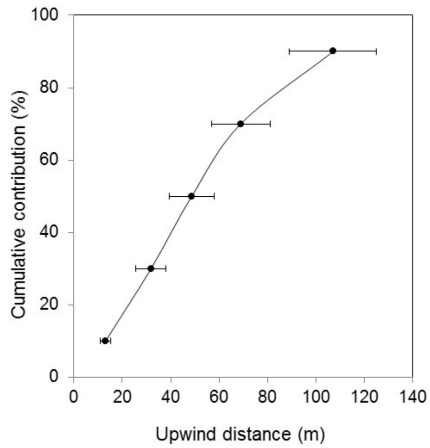


Fig. 4. The distributions of wind direction and speed at Turkey Run Landfill over the methane flux measurement period from April 26, 2012 to May 8, 2013.

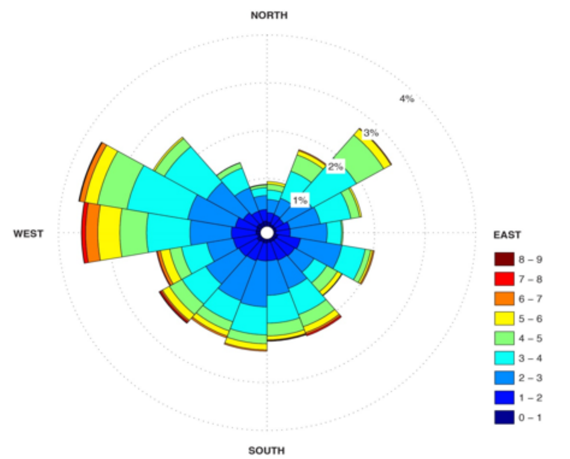


Fig. 5. Methane flux at different wind directions over the period of April 26, 2012 to May 8, 2013.

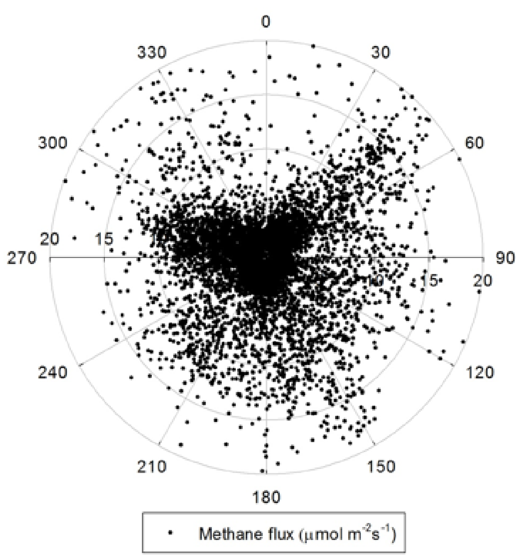
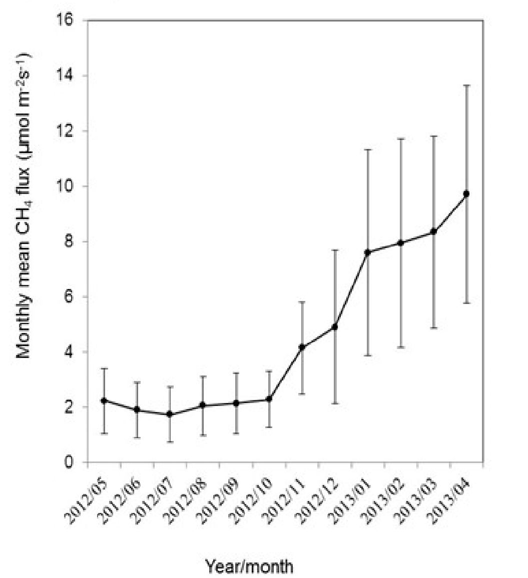


Fig. 6. Monthly average methane fluxes at Turkey Run Landfill from May 2012 to April 2013. Data are means ± standard deviations.



SUMMARY

The EC method is a standard method to measure methane emissions from large surfaces such as wetlands, rice fields, permafrost areas, etc. The EC system is able to run automatically for months and years providing good insights on both averaged methane emissions and their spatial and temporal variability. There are challenges applying the EC method to landfill methane emission measurement given the limited size and heterogeneity of a landfill. The data here indicate that the EC method can perform quite well in relation to the TC method, and both techniques can provide consistent methane emission results. The study also demonstrates that the EC approach can provide important information on the dynamics of landfill methane emissions.

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