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Short-term landfill methane emissions dependency on wind

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ABSTRACT

Short-term (2–10 h) variations of whole-landfill methane emissions have been observed in recent field studies using the tracer dilution method for emissions measurement. To investigate the cause of these variations, the tracer dilution method is applied using 1-min emissions measurements at Sandtown Landfill (Delaware, USA) for a 2-h measurement period. An atmospheric dispersion model is developed for this field test site, which is the first application of such modeling to evaluate atmospheric effects on gas plume transport from landfills. The model is used to examine three possible causes of observed temporal emissions variability: temporal variability of surface wind speed affecting whole landfill emissions, spatial variability of emissions due to local wind speed variations, and misaligned tracer gas release and methane emissions locations. At this site, atmospheric modeling indicates that variation in tracer dilution method emissions measurements may be caused by whole-landfill emissions variation with wind speed. Field data collected over the time period of the atmospheric model simulations corroborate this result: methane emissions are correlated with wind speed on the landfill surface with $R^2 = 0.51$ for data 2.5 m above ground, or $R^2 = 0.55$ using data 85 m above ground, with emissions increasing by up to a factor of 2 for an approximately 30% increase in wind speed. Although the atmospheric modeling and field test are conducted at a single landfill, the results suggest that wind-induced emissions may affect tracer dilution method emissions measurements at other landfills.

1. Introduction

Methane (CH_4) from biological decomposition of buried waste in landfills is considered an important source of anthropogenic CH_4 emissions (Scheehle et al., 2006). Measurement of CH_4 emissions is useful for evaluating landfill gas control measures and improving estimates of CH_4 emissions for greenhouse gas inventories. CH_4 emissions from landfills are not constant, with annual changes associated with aging of waste (Foster-Wittig et al., 2015) or changes in the composition of landfilled materials (Weitz et al., 2002; Allen et al., 1997), and seasonal variations due to changes in temperature and moisture content of cover soils that affect gas transport and methane oxidation (Wang et al., 2011; Chanton and Liptay, 2000; Stern et al., 2007).

Short-term emissions variations due to weather have also been reported. Czepiel et al. (2003) measured whole-landfill CH_4 emissions using the tracer dilution method (TDM) and found CH_4 emissions increased by a factor of five when barometric pressure dropped approximately 15 mbar over a 1-month period of emissions measurements. Xu et al. (2014) measured CH_4 emissions from portions of landfill cells using the eddy covariance method and attributed a 35-fold variation in emissions to barometric pressure variations.

Over even shorter time periods, wind speed has been implicated as a factor affecting CH_4 emissions (McBain et al., 2005; Rachor et al., 2013) – as wind speed increases, gas pressures fluctuate because of atmospheric turbulence at the landfill surface causing a pumping effect that increases emissions. Numerical modeling of gas transport processes in landfill cover soils suggests that pressure pumping caused by wind turbulence may increase CH_4 emissions up to four times that of the CH_4 diffusive flux for some soil conditions (Poulsen and Moldrup, 2006). While the effect of wind speed on CH_4 emissions has been observed in flux chamber (Rachor et al., 2013) and eddy covariance (McBain et al., 2005) measurements over portions of a landfill surface, there are no data indicating variations in whole-landfill CH_4 emissions because of wind speed.

TDM, also known as the tracer correlation or dynamic plume technique, was developed to quantify whole-landfill CH_4 emissions

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Nomenclature

TDM	tracer dilution method	VF1	Variable Flux 1
CRDS	cavity ring-down spectroscopy	VF2	Variable Flux 2
ARPS	advanced regional prediction system	3Pts	Three Point Flux
CF1	Constant Flux 1	AGL	above ground level
CF2	Constant Flux 2		

and has seen increased use in the past several years because of improved gas measurement technology (Foster-Wittig et al., 2015; Mønster et al., 2014, 2015). A tracer gas, traditionally sulfur hexafluoride (SF_6) or nitrous oxide (N_2O) but more recently acetylene (C_2H_2), is released at a known rate at multiple locations on the landfill which then mixes with CH_4 emissions from the landfill surface (Czepiel et al., 2003; Galle et al., 2001). Downwind of the source if the released tracer gas is sufficiently well mixed with emitted CH_4, the mass flux of CH_4 is calculated from the known mass flux of the tracer gas multiplied by the ratio of the CH_4 to tracer gas concentration

$$E_{CH_4} = E_T \frac{M_{CH_4}}{M_T} \frac{C_{CH_4}}{C_T} \quad (1)$$

where E_{CH_4} and E_T are CH_4 and tracer emissions rates, respectively, expressed as mass flowrate (kg/min); M_{CH_4} and M_T are the molecular weights of CH_4 and tracer; and C_{CH_4} and C_T are the concentrations of CH_4 and tracer above background (ppm). If measured at a fixed location, this concentration ratio can be averaged over time by regressing scatter plots of C_{CH_4} versus C_T to obtain the fitted slope used for the ratio C_{CH_4}/C_T in Eq. (1) (Galle et al., 2001; Börjesson et al., 2009). When measured by a moving vehicle that traverses the downwind gas plumes, similar scatter plots can be generated (Foster-Wittig et al., 2015; Mønster et al., 2014), or, more commonly, C_{CH_4} and C_T are integrated individually in space and the ratio of the two integrations are used to represent the ratio C_{CH_4}/C_T (Foster-Wittig et al., 2015; Mønster et al., 2014).

With increasing TDM applications, significant variations in measured CH_4 emissions have been reported for short measurement campaigns. For example, during measurement campaigns that ranged from 1.7 to 4.3 h, Scheutz et al. (2011) reported a coefficient of variation of CH_4 emissions up to 0.30. Similarly, in a recent study of nine Danish landfills where single measurement campaigns (2–10 h duration) were conducted at each landfill, the average coefficient of variation was 0.19 for the nine landfills with a maximum of 0.35 (Mønster et al., 2015). On the other hand, when the TDM method was tested with controlled releases of CH_4 and tracer (Mønster et al., 2014), the coefficient of variation was much smaller: for three tracer/CH_4 release configurations and measurements at three downwind transects, the mean coefficient of variation was 0.05 with maximum of 0.15, which occurred for the configuration with significant misalignment between CH_4 and tracer and for measurements close to the points of gas release. The cause of the increased coefficient of variation for landfill CH_4 emissions versus controlled CH_4 releases is unclear: it may be due to misalignment of tracer release and regions of CH_4 emissions, short-term variations in emissions possibly due to wind, or other factors.

The primary objective of this work is to determine if short-term variations in whole-landfill CH_4 emissions measured with TDM might be due to variations in wind speed. If wind affects whole-landfill CH_4 emissions, in some situations TDM may result in biased estimates of emissions, since TDM requires sufficient wind speed to generate well-mixed gas plumes downwind of the landfill (Foster-Wittig et al., 2015), and thus measurements are not possible under low wind speeds (Foster-Wittig et al., 2015; Galle et al., 2001). A secondary objective is to evaluate the utility of atmospheric dispersion modeling to understand the influence of atmospheric conditions on landfill emissions measurements requiring sampling of landfill gas plumes.

To accomplish these objectives, CH_4 emissions data were collected using TDM from the Sandtown Landfill in Delaware (USA) for a short-term experiment in March 2010. Correlations between wind conditions on the landfill surface and CH_4 emissions were explored with field data. An atmospheric dispersion model was developed for the site and used for three purposes: to determine the travel time of emissions from the landfill surface to a downwind measurement location; to refine data filtering techniques for TDM, since in the atmospheric model CH_4 emissions were known and could be compared with TDM results from analysis of model output; and to assess if temporal variation in emissions determined from TDM might be caused by misalignment of tracer/CH_4 emissions locations or wind conditions. Field data and numerical model results were collected at one downwind location at two measurement heights, at the ground surface and at approximately 85 m above ground to evaluate the benefit of above ground measurements on TDM.

2. Materials and methods

2.1. Site description

The Sandtown Landfill has an active landfill gas collection system in all landfill cells and ongoing waste disposal activities. Area A–B (110,000 m^2) in Fig. 1 was filled with 532,000 tons of household waste from 1980 to 1988 and is now closed and equipped with a final cover. A total of 1,226,000 tons of waste were landfilled in Area C and D (170,000 m^2) from 1988 to 1998 and these regions have intermediate covers. Area E (132,000 m^2) is an active cell where 2 million tons of waste have been landfilled since 1999: portions of Area E have intermediate and daily cover soils. The landfill rises 40 m above the surrounding topography and is located in a coastal plain with minimal variations in ground elevation for a 100 km radius surrounding the site. The landfill is in a rural area with low traffic density and is surrounded by farms with 25–30 m high pine trees.

2.2. Field emissions measurements

TDM was utilized to quantify CH_4 emissions from the Sandtown Landfill. Details of the method are found elsewhere (Czepiel et al., 2003; Foster-Wittig et al., 2015; Mønster et al., 2015). In this application, C_2H_2 was selected as the tracer gas (Foster-Wittig et al., 2015; Mønster et al., 2014). Three C_2H_2 gas cylinders were located on the upstream edge of the active landfill region on Area E (Fig. 1), identified as the main CH_4 source during preliminary ground-level atmospheric CH_4 measurements around the landfill in March 2010. The gas cylinders were arranged 70 m apart in a line perpendicular to the mean wind direction. Mass flow controllers were used to