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Remote sensing of methane and nitrous oxide fluxes from waste incineration

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ABSTRACT

Incomplete combustion processes lead to the formation of many gaseous byproducts that can be challenging to monitor in flue gas released via chimneys. This study presents ground-based remote sensing approaches to make greenhouse gas (GHG) flux measurements of methane (CH₄) and nitrous oxide (N₂O) from a waste incineration chimney at distances of 150–200 m. The study found emission of N₂O (corresponding to 30–40 t yr⁻¹), which is a consequence of adding the reduction agent urea to decrease NO_x emissions due to NO_x regulation; a procedure that instead increases N₂O emissions (which is approximately 300 times more potent as a GHG than CO₂ on a 100-year time scale). CH₄ emissions of 7–11 t yr⁻¹ was also detected from the studied chimney despite the usage of a high incineration temperature. For this particular plant, local knowledge is high and emission estimates at corresponding levels have been reported previously. However, emissions of CH₄ are often not included in GHG emission inventories for waste incineration. This study highlights the importance of monitoring combustion processes, and shows the possibility of surveying CH₄ and N₂O emissions from waste incineration at distances of several hundred meters.

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1. Introduction

Besides water vapor (H₂O), the main GHGs in the Earth's atmosphere are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Although CO₂ is the most heavily monitored GHG, CH₄ and N₂O have mass-based greenhouse warming potentials (GWP) that are 86 and 268 times higher than CO₂ on a 20-year time scale (IPCC, 2013). A recent global inventory also calls for additional attention to CH₄ and N₂O as their 100-year GWP emissions offset the terrestrial land CO₂ GWP sink (Tian et al., 2016). In this context, all activities contributing to emissions of CH₄ and N₂O are important for the large-scale GHG balances.

Incomplete combustion is known to produce CH₄ and N₂O, but quantities released are uncertain. This study focuses on such emissions from combustion of waste, but the general approach presented can be applied more broadly on a wide range of combustion processes.

Waste handling represents one area of importance for societal GHG emissions. Landfills are known to produce and emit large amounts of CH₄ for several decades (Bogner et al., 2008) with many examples of large emissions available in literature (e.g. Hegde

et al., 2003; Jha et al., 2008; Lando et al., 2017). Waste incineration is a beneficial alternative to landfills in releasing more CO₂ than CH₄ while generating energy from the waste (Giusti, 2009). There are, however, uncertainties regarding GHG emissions of CO₂, CH₄, and N₂O from waste incineration as emissions may depend heavily on factors such as the type of waste used for incineration, the incineration temperature, flue gas cleaning, and the type of incineration facility (Harris et al., 2015).

Due to the high combustion temperatures frequently used in waste incineration, emissions of CH₄ are often assumed to be small and therefore not considered in emission estimates (Bogner et al., 2008; IPCC, 2006). N₂O, on the other hand, can survive higher temperatures than CH₄. There are several types of waste incineration that could produce N₂O emissions, such as sewage sludge incineration, municipal solid waste incineration, biomass combustion for energy production, and incineration of waste-based fuels with high nitrogen content (Svoboda et al., 2006). Waste incineration can also produce NO_x emissions, which affect air quality, and is related to photochemical smog, acid rain, and tropospheric ozone formation (Skalska et al., 2010). Many incineration plants therefore reduce the amount of NO_x emissions by adding a reduction agent, which in the case of urea can produce a NO_x to N₂O conversion rate of up to 30% (Grosso et al., 2009). Hence there can be a trade-off between releasing NO_x or N₂O upon incineration, and because

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NO_x is regulated in some cases while N₂O is not, the incineration plants may favor NO_x conversion to N₂O. Consequently, the N₂O emissions from municipal waste incineration have been shown to vary greatly between incineration plants, with studies indicating emissions in the ranges 11–293 g N₂O t⁻¹ waste (Barton and Atwater, 2002) and 4–153 g N₂O t⁻¹ waste (Harris et al., 2015; Park et al., 2011). Given the high GWP of N₂O this can correspond to emissions as high as 80 kg CO₂e t⁻¹ waste. The amount of CO₂ emissions varies with waste type but as an example Hutton et al. (2009) obtains 55 kg CO₂ t⁻¹ waste for their case study of Melbourne, Australia. In the same study, a landfill will 60% gas capture results in CH₄ emissions of 508 kg CO₂e t⁻¹ waste on a 20-year timescale. In other cases, depending on the efficiency of landfill gas capture, incineration technology, and waste type, incineration can have higher GHG emissions than landfilling. Assamoi and Lawryshyn (2012), using data from Toronto, Canada, shows that because incineration has the potential to generate significantly more electricity than landfilling, a corresponding offset in the emissions makes incineration a better option environmentally. The impact from incineration however has a high dependency on the technology used (e.g. NO_x conversion to N₂O) and thus the N₂O emissions produced.

Waste incineration is increasing worldwide as the preferred method for waste disposal due to concerns about space requirements, the risk of soil and water pollution associated with landfilling, and the added benefit of energy recovery associated with incineration (Astrup et al., 2009; Hoornweg and Bhada-Tata, 2012). Therefore, as incineration replaces landfilling, accurate estimates of GHG emissions, taking the different plants into account, fuels, and techniques, are essential for accounting for the emissions in the waste sector.

In-situ sampling of hot flue-gas has previously been used to sample GHG emissions from waste incineration, often using gas bags to collect samples and a gas chromatograph or Fourier Transform Infrared (FTIR) spectrometer for analyzing mixing ratios (e.g. Harris et al., 2015; Park et al., 2011). This article presents an alternative method based on a sensitive remote sensing technique from the ground for non-intrusive, direct measurements of both CH₄ and N₂O fluxes from waste incineration. The method makes it possible to do measurements from distances of several hundred meters, and can also be applied to heat and power plants that use other types of fuels than waste, for example fossil fuels.

2. Materials and methods

A customized Long Wave Imaging Fourier Transform Spectrometer (IFTS) (Telops Inc., Quebec City, Canada) was used in this study, working in a narrow thermal IR spectral region, optimized for the 7.7 μm band of CH₄, which also includes many N₂O spectral features. It has a settable spectral resolution and the Focal Plane

Array (FPA) has a resolution of 320 × 256 pixels, yielding a field of view (FOV) of 25 × 20 degrees with a 0.25× de-magnifying telescope. The FPA is cooled down to 74 K and its resolution can be windowed down in order to speed up the data acquisition. The instrument has previously been described in Gålfalk et al. (2016).

Remote sensing from the ground was used to measure fluxes of CH₄ and N₂O from the chimney of a waste incineration plant using clear cold sky as background. Measurements were made on two occasions, from distances of 153 and 183 m, using spectral resolutions of 1 and 0.25 cm⁻¹, respectively.

Table 1 lists a summary of the measurements and instrument settings used. Individual exposure times were 1.5 ms, and the total number of exposures for each interferogram were 6,320 and 10,113 for spectral resolutions of 1 cm⁻¹ and 0.25 cm⁻¹, respectively. Radiometric calibration was made in the field using two built in black bodies that can be slewed in front of the instrument, covering the lens, and imaged with settable temperatures. Additional field equipment include a laser rangefinder (Newcon LRM 2200SI) used for measuring distances to selected points on the chimney, which when combined with the corresponding hyperspectral images, can be used to obtain the amount of CH₄, N₂O and H₂O in the foreground towards the chimney, a rugged field computer (Stealth), a Honda EU 30i electrical generator as a power source for the computer and IFTS, and a portable weather station (Vaisala WXT520).

The system takes about one hour for the temperatures of the different components to stabilize. The time needed for data acquisition (including calibration measurements) varies a lot depending on the target being measured (spectral resolution, the area of the detector used, motions in the scene, additional measurements sometimes required such as the sky). Table 1 gives the durations used for the measurements in the current study (in addition to the startup time of one hour). It is difficult to specify a total cost for the method as the camera used here was the first of its kind and the price is likely to decrease in the future. However, in this study the cost for the method was approximately 2000 USD per day of image acquisition (currency value per the year 2017), including camera hardware down payments and working time in the field and for later image processing.

An overview of the chimney with selected types of measurement points is presented in Fig. 1. The camera-chimney distance was measured using an optical range finder, and the ambient levels of H₂O, CH₄, and N₂O measured using lines of sight below the chimney outlet with the chimney as background (point 1 in Fig. 1B). The reflectivity of the chimney can introduce systematic errors in the ambient levels as these become more difficult to fit, this however only has a small effect on the calculated emissions (below a few percent in tests). This uncertainty can if needed be reduced by using another background, with lower reflectivity than the chimney, for calculation of the ambient concentrations.

Table 1
Measurement log for the IFTS. Cubes denote full sets of 3-dimensional data (spatial x and y dimensions plus the IR spectrum in each image pixel as the third dimension). Duration represents the total imaging acquisition time.

Target	Spectral resolution (cm ⁻¹)	Cubes	Images per cube	Imaging frequency (s ⁻¹)	Duration (min)
<i>Occasion 1 (March 27, 2013)</i>					
Blackbodies	1	2 × 15	6320	328	9.6
Chimney	1	180	6320	328	57.8
Sky	1	45	6320	328	14.4
Blackbodies	1	2 × 45	6320	328	28.9
<i>Occasion 2 (October 11, 2013)</i>					
Blackbodies	0.25	2 × 30	10,113	473	21.4
Chimney	0.25	40	10,113	473	14.3
Blackbodies	0.25	2 × 30	10,113	473	21.4

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