Measuring Ammonia Emissions From Manured Fields With a Mobile Lidar System

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ABSTRACT

Ammonia contributes to acidification of soil, surface water and ground water, and causes eutrophication. In the Netherlands, most of the ammonia found in the environment originates from agricultural activities. The emission of manured fields is still an uncertain factor. This paper reports on the addition to an existing mobile lidar system, already capable of measuring NO_2 and SO_2, the capability of measuring ammonia.

The lidar system uses the DIAL technique. To measure ammonia, the absorption peak at 208.25 nm is used. The entire system is housed in a fully self-supporting mobile laboratory, enabling it to take position downwind from manured fields and measure the ammonia emission.

In a field campaign, the lidar was tested, together with a novel mobile tuneable diode laser system. The instruments were compared to each other and to the micrometeorological mass balance method, an established measurement technique.

In this campaign, similar emission patterns were observed by all three measurement methods. Further findings were that, while the bulk of the emission took place during the first hours, the second day after application contributed considerably to the total emission. Finally, on grassland, ammonia emissions were higher than would have been expected on the basis of previous experiments with the mass balance method, but within the range of those past experiments.

1. INTRODUCTION

Excessive emissions of ammonia into the atmosphere are undesirable. The compound, after deposition, contributes to acidification of soil, surface water and ground water, and causes eutrophication. In natural environments, this leads to a loss of biodiversity, because plant species that thrive on nutrient-rich soil replace the more varied flora that is found on poorer soils.

In the Netherlands, most of the ammonia found in the environment originates from agricultural activities. Its main source is animal manure. Ammonia is emitted from stables, from manure dropped by grazing livestock, and from manure spread onto fields. The latter emission source is still an uncertain factor in the Dutch national ammonia emission budget [1]. The bulk of the emission occurs in the first hours after manure application. The total amount emitted depends strongly on weather conditions, field conditions and on the application technique used. The emissions associated with different application techniques were evaluated in the past on small experimental plots, but little information is available on emissions from entire fields.

In this paper, the use of a mobile lidar system to measure the ammonia emissions of manured fields is described, as well as a comparison of the results with those obtained through two other measurement techniques.

2. THE MOBILE LIDAR

Lidar, short for *light detection and ranging*, is a technique similar to radar, but it uses light rather than radio pulses. A differential absorption lidar (or DIAL) is able to remotely measure the concentration of a trace gas in the atmosphere [2]. This DIAL technique makes use of the difference in light absorption by the trace gas to be measured. In effect, the instrument is “tuned” to the gas by selecting a set of two or more wavelengths that are absorbed differently by that gas.

The mobile lidar system reported on here is designed with flexibility in mind, so that both changing the gas that is being measured and adding the capability to measure a new gas is as straightforward as possible. At the moment, the system is capable of measuring NO_2 (see [3] and [4]), SO_2 (see [5]) and NH_3 (see [6]).

The mobile lidar measures NO_2 and SO_2 in the visible and ultraviolet spectral ranges, respectively. To add the capability of measuring NH_3 with a minimum of changes to the configuration, an absorption line in the deep ultraviolet was selected, at 208.25 nm. The wavelengths used are 207.897 and 208.253 nm, see Figure 1.

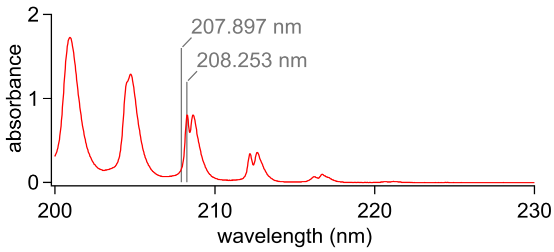

Figure 1. *Absorption spectrum of gaseous ammonia, showing the wavelengths used.*

2.1 Lidar System Design

The lidar system design is outlined in Figure 2. It consists of an emitter unit, a receiver unit, a spectrophotometer unit (not shown) and a processing and control unit (not shown). The entire system is housed in a fully self-supporting mobile laboratory.

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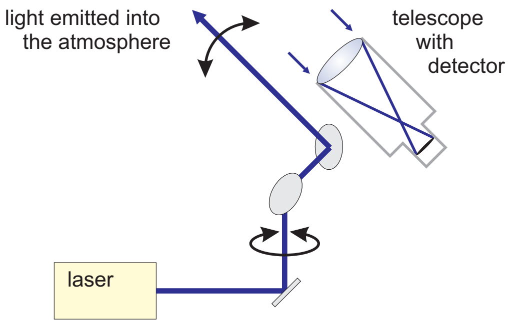

Figure 2. *Scheme of the lidar system design.*

2.2 The Emitter Unit

Light pulses are emitted by a pump laser - dye laser combination. The pump laser is a Spectra-Physics Nd:YAG laser, running at 30 Hz. The third harmonic output of this laser is used to pump a Sirah dye laser. For measuring ammonia the dye Exalite 417 is used. The blue light produced by this set-up is frequency doubled, which results in UV laser pulses with an energy of about 1.3 mJ, a linewidth of 1.2 pm, and a duration of about 10 ns. The divergence of the laser beam is 0.5 mrad. Its exact wavelength is permanently monitored with a wavemeter.

The laser beam is directed towards the atmosphere through a set of mirrors and prisms. The last two of these are steerable, so that the beam can be pointed at any direction around the instrument: in the vertical plane from slightly below the horizon to the zenith, in the horizontal plane almost 360º round.

2.3 The Receiver Unit

The receiver unit consists of a small (5 cm aperture), home-built refractive telescope, an interference filter and a photomultiplier tube. The entire receiver is mounted on the same platform as the last mirror of the emitter unit, so that the telescope always looks in the direction that the laser beam is pointing. This receiver system allows the measurement of concentration values between 35 and 105 m range from the lidar.

2.4 The Mobile Laboratory

The entire system is housed in a custom built mobile laboratory, 8 m long, 2.5 m wide and 2.3 m high, mounted on a vehicle (Figure 3). It is fully self-contained: it has a generator, climate control and a system to provide the laser with cooling water. While measuring, the laboratory floor is stabilised by underpinning the entire vehicle with hydraulically retractable supports.

Figure 3. *The mobile lidar, while measuring.*

3. MEASURING AMMONIA EMISSIONS

3.1 Measurement Procedure

To determine the emission of a manured field from a set of concentration measurements the following procedure is adopted. The lidar measures concentrations along a set of directions, all in the same horizontal direction but with increasing elevations (Figure 4). This way, an image of the ammonia concentration distribution in a vertical plane is obtained. This plane is positioned downwind from the manured field, so that the wind carries any emitted ammonia through it. A measured concentration distribution is shown in Figure 5.

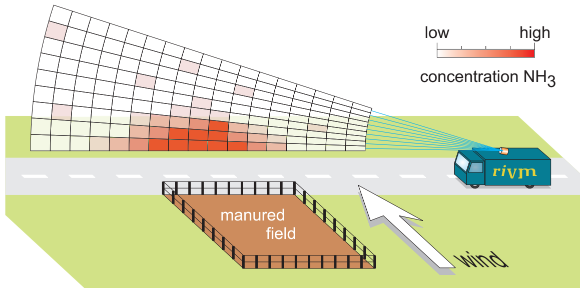

Figure 4. *Scheme showing how the lidar is used to measure the ammonia emission of a manured field.*

In this two-dimensional concentration distribution, all concentration values on the same altitude are summed and then multiplied by the wind speed at that altitude (see also 3.2 below). All values thus obtained are summed to arrive at the total flux of ammonia passing through the vertical plane, per unit of time. Finally, this flux is divided by the emitting surface.

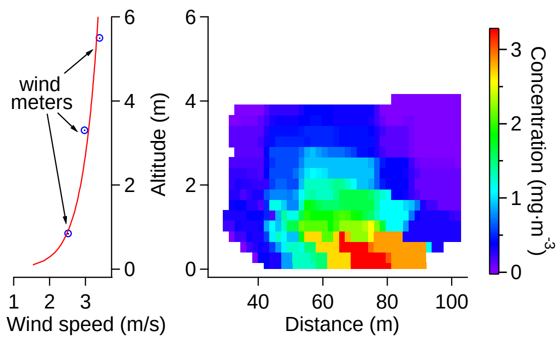

Figure 5. *Left: wind profile. Right: example of a 2D cross section of an ammonia plume.*

3.2 The Wind Profile

To obtain the wind profile, a 5.5 m telescopic mast is used, fitted with wind meters at three different heights. These measure wind speed and wind direction, simultaneously with the lidar measurements. Through the wind speeds a logarithmic curve is fitted (Figure 5), this is the profile used in the flux calculations.

4. MEASUREMENT CAMPAIGN

4.1 Campaign Set-Up

Together with the Energy Research Centre of the Netherlands (ECN) and Wageningen University and Research Centre (WUR) a measurement campaign was conducted, consisting of six experiments on two different farms, plus a test experiment on an artificial source.

The aims of the campaign were twofold. First, the aim was to test the ability to measure ammonia emissions, not only of the lidar, but also of a novel mobile Tuneable Diode Laser system (TDL), built and operated by ECN [6]. In one of the six experiments, WUR also operated the micrometeorological mass balance technique, an established measurement method [8]. The campaign is more extensively described in [6].

The second aim was to investigate the ammonia emissions from fields that were manured in their entirety, especially grassland fields, under normal farming conditions.

Figure 6. *Manure spreading during an experiment, with the mobile lidar in the background.*

The first three experiments were on a test farm (Figure 6). In these experiments, surface spreading was used to apply the manure onto arable land. The last three experiments took place on the grasslands of a commercial dairy farm. Here, narrow-band application was used, and manure was applied onto grassland. A selection of the results is presented below.

4.2 Measurement Results

4.2.1 Results for Arable Land

On one of the experiments on the test farm was the only occasion when all three measurement techniques were available. In this experiment, manure was applied in a small circle onto bare arable land. The results are presented in Figure 7. On the left axis are shown the emission rates, measured with the mobile lidar and with the TDL. On the right axis are shown the cumulative emissions derived from these measurements, as well as the cumulative emission measured with the micrometeorological mass balance method. The grey shading in the background denotes the night periods, the day is left white. The moment of manure application is indicated as well.

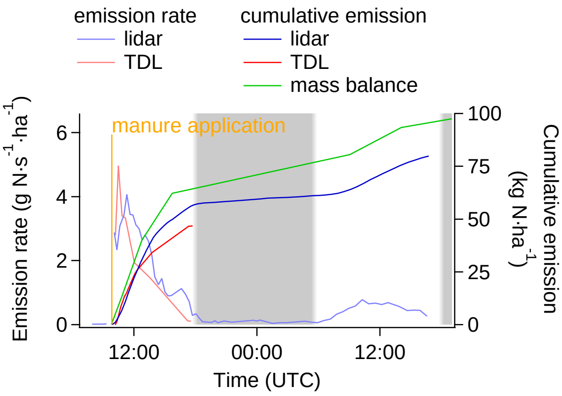

Figure 7. *Emission rates (left axis) and cumulative emissions (right axis) of a small manured circle on arable land.*

The emission rates observed by both the TDL and the lidar were similar. Note that both instruments measured a maximum in the rate some time after the manure had been applied.

All methods measured similar cumulative emission patterns, while the mass balance method turned out slightly higher emissions. A notable feature is that both the lidar and the mass balance measured a significant emission on the second day, amounting to 25-30% of the emission found on the first day.

For the lidar, an estimate was made of the precision of the instrument. This turned out to be 20% in the final emission rate determined. However, this number may be considered to be an upper limit; it contains all variations, including changes in the emission due to changes in the wind speed and in the solar irradiation.

4.2.2 Results for Grassland

Figure 8 shows the measurement results for on of the experiments on the grasslands of the commercial dairy farm, the only occasion on that location when both the TDL and the lidar performed measurements. Results from a chemical denuder measurement system that sampled air downwind from the field are shown in the graph as well. In this experiment, a large section of a field was manured.

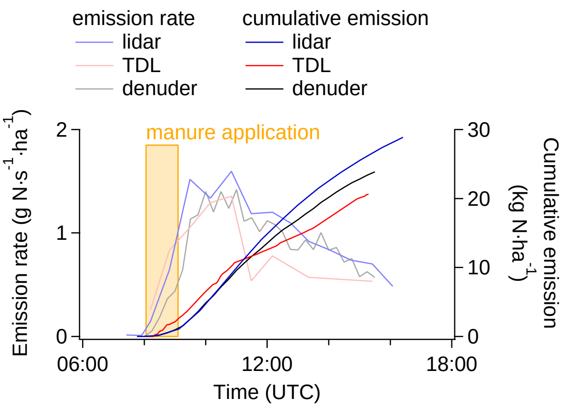

Figure 8. *Emission rates (left axis) and cumulative emissions (right axis) of a manured field of grassland.*

The emission trends measured with the TDL, the lidar and the chemical denuder were comparable. The amount of nitrogen evaporated after eight hours was about 30% of the total available ammoniacal nitrogen (TAN). This is high; the average from past experiments is 26% after 96 hours, but it is within the range of these past experiments (8 to 52%) [9].

5. CONCLUSIONS

The existing mobile lidar instrument was modified to measure ammonia concentrations. It was used alongside a novel TDL instrument and the established mass balance technique in a number of experiments. In these experiments, similar emission patterns were observed by all three instruments.

The experiment on arable land spanned two consecutive days. While the largest emission was found on the first day of the experiment, a significant emission was observed on the second day as well. This emission amounted to 25% of the emission measured during the first day.

In the experiments on grassland, about 30% of the available total ammoniacal nitrogen (TAN) evaporated during the first eight hours. Based on the past experiments, the percentage of TAN expected to have evaporated after 96 hours was estimated to be on average 26%. Although these figures cannot be compared directly, it can be stated that the emissions found in the experiments on grassland are relatively high.

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