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Abstract

Efficient Methane Monitoring with Low-Cost Chemical Sensors and Machine Learning †

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Abstract: We present a method to monitor methane at atmospheric concentrations with errors in the order of tens of parts per billion. We use machine learning techniques and periodic calibrations with reference equipment to quantify methane from the readings of an electronic nose. The results obtained demonstrate versatile and robust solution that outputs adequate concentrations in a variety of different cases studied, including indoor and outdoor environments with emissions arising from natural or anthropogenic sources. Our strategy opens the path to a wide-spread use of low-cost sensor system networks for greenhouse gas monitoring.

Keywords: methane; electronic nose; environmental monitoring; machine learning; gas sensors; low-cost

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1. Introduction

Atmospheric methane (CH4) has a 100-year global warming potential 28–34 times greater than carbon dioxide by mass [1]. Its concentration is rapidly and irregularly increasing for partly unclear reasons because CH4 emission sources and sinks are poorly constrained [2]. Hence, better ways to monitor CH4 are crucial to reveal source-sink dynamics and determine the mitigation efforts needed. Cost efficient sensors are an appealing solution to offer the needed complementarity to other broader and more expensive methods such as satellite surveillance, aircraft sampling, or ground-based micrometeorological measurements [3]. However, versatile systematic calibration and cross-interference compensation for cost efficient sensors are issues that remain elusive. While laboratory calibrations can produce accurate calibration curves, field use suffers from large interferences from water vapor (H2O), ambient temperature, and barometric pressure. Thus, multi-dimensional reliable and versatile outdoor calibration is needed. Here, we approach this challenge by analyzing the readings of an electronic nose (e-nose), equipped with multiple cost efficient sensors, with multivariate statistics to successfully monitor CH4 concentrations in outdoor environments.

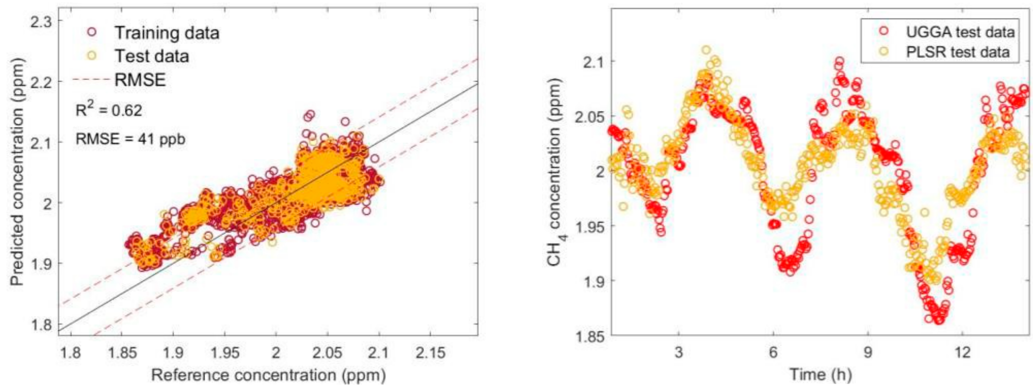
2. Materials and Methods

Our e-noses consist of a tailor-made printed circuit board that accommodates three metal-oxide gas sensors to measure CH4, one sensor to measure relative humidity, temperature, and barometric pressure, an Arduino MKR WAN 1310, an Arduino MKR SD Proto Shield, and an Arduino MKR GPS Shield to monitor, log, geotag, and timestamp the data from the sensors.

The data obtained from different field sites was used to train partial least squares regression (PLSR) models and the results were benchmarked against CH4 concentrations monitored with reference equipment.

3. Discussion

Figure 1 shows the results of the PLSR model prepared for one of our field measurements, where H2O varied between 9.6 and 12.1 g·m−3 (31 to 78% relative humidity), ambient temperatures from 18 to 31 °C, and pressures from 1005 to 1009 hPa. The coefficient of determination, R2, is 0.62 and the root mean squared error (RMSE) is 41 ppb (Figure 1a). When testing the model (Figure 1b), we obtained trends that fit the reference (UGGA). The R2 values obtained for other field sites are up to 0.90, and RMSE values are always below 7% of the concentration range studied.



(**a**) (**b**)

Figure 1. (**a**) Results from partial least squares regression model trained and tested with data acquired outdoors in a private garden in a suburban area close to a forest during autumn in Sweden, and (**b**) temporal evolution of the test data compared to data reported by means of reference equipment.

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