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GREENLITE™: A YEAR OF CARBON DIOXIDE MONITORING OVER PARIS, FRANCE, AND RECENT PROGRESS IN MONITORING METHANE

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ABSTRACT

GreenLITE™ is a ground-based laser absorption spectroscopy system capable of measuring and mapping CO_2 concentrations over areas up to 25 km^2. The system was deployed for COP21 as a demonstration and has now completed a year of CO_2 measurements over the city of Paris, France. We will discuss lessons learned and relevant data from the year-long deployment. Recently, the system has demonstrated the same measurement capability for CH_4, and results from preliminary testing are presented.

1 INTRODUCTION

It has long been recognized that prediction of human induced effects on climate change requires a deeper understanding of the overall carbon cycle. The two primary greenhouse gases humans are contributing which can impact global climate change are carbon dioxide (CO_2) and methane (CH_4), and although there has been significant progress in understanding emissions of these gases, there are still many gaps in our accounting. Furthermore, the primary sources of the human generation of these gases are connected to urban areas, and not surprisingly this is dominated by large metropolitan areas. With this factor in mind, and a growing global desire to limit the human impact on climate change, the 21st Conference of Parties (COP21) met in Paris, France, in December 2015 to discuss global commitments for reduction of emissions. Uncertainties in the emissions of greenhouse gases from cities can be large, and point measurements within the city structure experience large local variability and are ill suited for inversions, leaving upwind and downwind gradients as the best source of urban concentration data for inversions [1].

Although these methods have been shown to significantly reduce uncertainties between bottom-up and top-down estimates of urban emissions, they provide little information on the spatial distribution within the city boundaries, and further improvement is needed to accurately evaluate mitigation results and further reduce emissions. To this end, an integrated-path differential absorption laser-based system was deployed to Paris in November 2015. The system provided spatially averaged concentration measurements over a 25 km^2 area within the heart of the city, along with estimates of the time varying 2-D spatial distribution. The following sections describe the measurement approach and review results from a full year of CO_2 measurements and recent local experiments using a similar system for measuring CH_4.

2 METHODOLOGY

The Greenhouse gas Laser Imaging Tomography Experiment (GreenLITE™) utilizes a unique continuous wave laser absorption spectroscopy approach to enable long-path atmospheric concentration measurements originally developed for an airborne instrument described in reference [2].

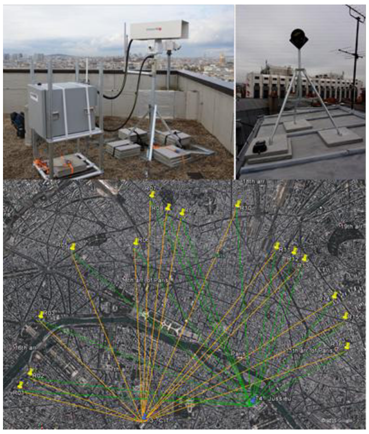


Figure 1: Top left – A GreenLITE™ transceiver. Top right – An installed GreenLITE™ reflector. Bottom – System layout as installed in Paris with 15 reflectors and two transceivers covering ~25 km^2.

In addition to the long-path concentration measurements, GreenLITE™ utilizes a configuration that results in multiple intersecting paths, which can be used to provide estimates of the 2-D spatial distribution of the concentration within the field of regard.

2.1 Measurement Description

The GreenLITE™ transceivers deployed in Paris, France, each use two fiber-coupled distributed feedback lasers (DFBs) to generate laser light at a wavelength that is absorbed by the gas of interest (1571.112 nm) and another nearby wavelength that has significantly lower absorption (1571.052 nm). Both wavelengths are subjected to unique low-frequency amplitude modulations and combined in fiber before being simultaneously transmitted via an F/2 25.4 mm off-axis parabola (OAP) to a 127 mm hollow retroreflector, which returns the light to be collected by a custom 152.4 mm F/4 coaxial OAP-to-fiber receiver telescope and sent to a room-temperature 1.5 mm InGaAs detector. The electrical signal is then amplified via a transimpedance amplifier and digitized. The return signal amplitude and phase from the individual wavelengths are then reconstructed using a digital lock-in amplifier approach. Prior to transmission, a small portion of the beam is sent to a reference InGaAs detector in order to monitor the relative transmitted signal levels for normalizing the return. A simple block diagram is given in Figure 2.

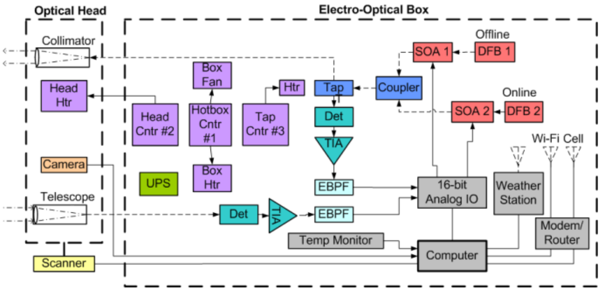
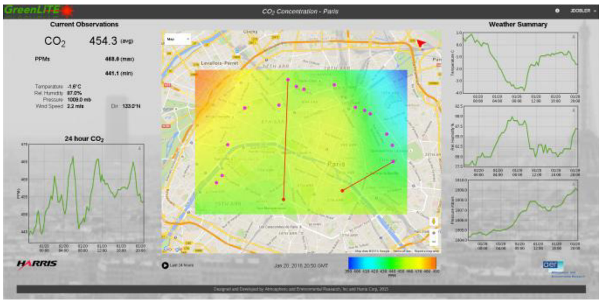


Figure 2: Basic block diagram of the GreenLITE™ transceiver. Acronyms in the figure are as follows: Htr – heater, Cntr – controller, UPS – uninterruptible power supply, Det – detector, TIA – transimpedance amplifier, EBPF – electronic bandpass filter, SOA – semiconductor optical amplifier, DFB – distributed feedback laser, and IO – input/output.

The resulting signals are used to calculate the differential absorption between the two wavelengths over the path-length determined by the transmitted channel phase delay relative to the reference phase. The transceivers are mechanically scanned to each of the 15 retroreflectors in sequence, and require 10 seconds at each to retrieve the differential transmission along the path defined by the transceiver and reflector locations as illustrated in Figure 1. The differential absorption information is sent, along with atmospheric state data (temperature, pressure, relative humidity, wind speed and direction), to a cloud-based custom signal processing software package. The information is used in conjunction with a radiative transfer model (LBLRTM [3]) to convert the observed data into a dry-air mole-fraction value, in parts per million by volume (ppmv), for each 10 second measurement. The combination of measurements from the overlapping paths is used in a sparsely-sampled tomographic-like reconstruction algorithm to produce the estimate of the 2-D spatial distribution. Additional information describing the system can be found in references [4, 5]. The data products from the processed system data are continually streamed near-real-time via a user web interface.

3 RESULTS

The GreenLITE™ system operated continuously over the city of Paris, France, from November 04, 2015, to November 14, 2016. An example of a typical web-based output at a given point in time is provided in Figure 3.



CO_2 454.3 (avg)
PPMs 468.0 (max)
441.1 (min)
Temperature -1.6°C
Rel. Humidity 87.0%
Pressure 1009.0 mb
Wind Speed 2.2 m/s Dir 133.0°N

Figure 3: GreenLITE™ web interface output for 1/20/2016 at 20:50 GMT. The left-hand side shows the current spatially averaged CO_2 concentration and the concentration as a function of time (plotted in lower left corner). Also on the left, the maximum and minimum CO_2 concentrations across the field are shown with the current atmospheric state data. The center shows the 2-D estimate of the spatial distribution. The right-hand side shows the measured weather parameters.

Over the one-year period, 3.57 million (M) raw differential transmission samples were collected, 1.91 M samples passed quality control with dry air mole fraction retrieved, and 64 thousand tomographic 2-D reconstructions were generated. Out of the 376 days the instrument was installed, valid measurements were collected on all but 6 days, resulting in 370 days of operation.

There were two primary instruments that had data available during the deployment of the GreenLITE™ system. A Picarro cavity ring-down spectrometer (CRDS) and a Thermo Fisher Delta Ray had coincident measurements available during the Paris deployment; comparisons are shown in Figure 4.

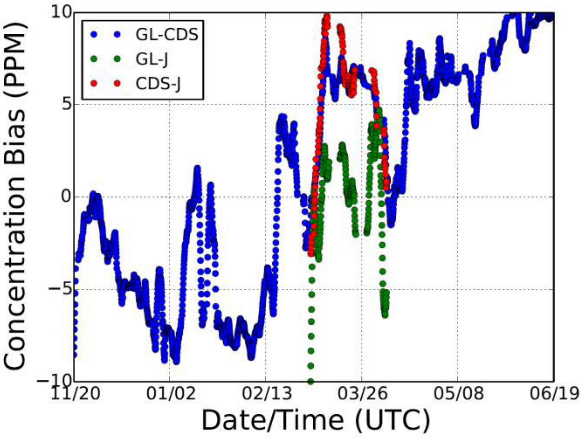


Figure 4: Comparison of GreenLITE™ (GL) to a Picarro CRDS (CDS) located outside of the GL footprint and the GL versus the Thermo Fisher Delta Ray (J), as well as the CDS versus J.

In general, the in situ instruments agreed well with GreenLITE™, especially the Thermo Fisher Delta Ray, which was located near one of the GreenLITE™ transceivers for a 5-week period in March - April 2016. The only long-term record was from the Picarro at the CDS site, which showed an offset of about 5.2 ppm, on average, over the year, and showed a seasonal variation of about 5 ppm, as shown in Figure 5.

An example of other interesting observations over the course of the experiment includes information on daily cycles that are clearly driven by human activity. Figure 6 shows an example of this, comparing weekday diurnal cycles to weekend diurnal cycles. Other things that were seen are clear correlations between CO_2 and nitrogen dioxide (NO_2), and an anti-correlation between CO_2 and ozone (O_3), using GreenLITE™ and AirParif data.

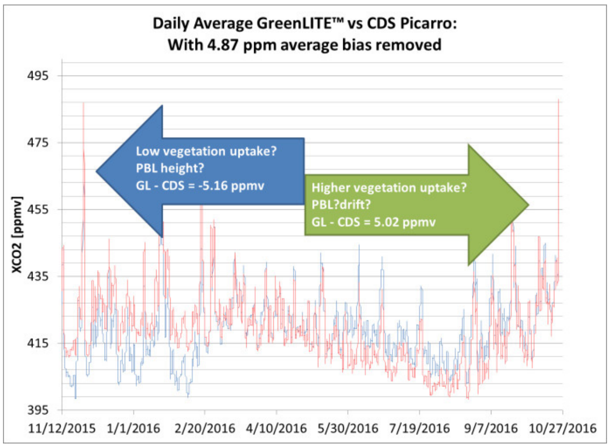


Figure 5: Full-year comparison of hourly averages between GreenLITE™ and the CDS Picarro instrument with the average bias removed. Residual error is nearly equal but in opposite directions from Nov - April and May - Oct. Further experiments are required to understand these differences, but they appear to be related to the biogenic signature seen by the Picarro located at the CDS site, which is in an urban park.

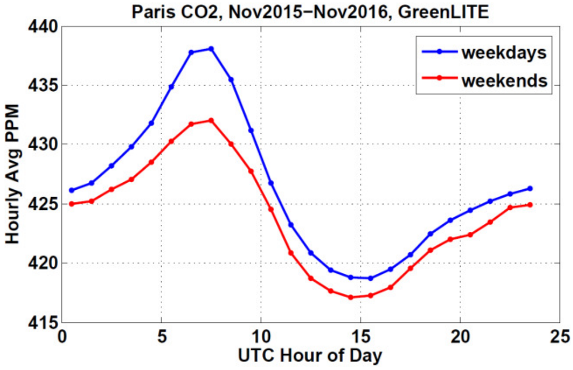


Figure 6: An example of GreenLITE™ observations clearly capturing differences from weekdays to weekends driven by human activity.

Recently, GreenLITE™ has undergone experiments at the Harris Farm Test Site in New Haven, Indiana, to demonstrate the same capability for CH_4 monitoring as that demonstrated in Paris for CO_2. This included a controlled release, which was clearly identified above the background, as seen in Figure 7. The left-hand plots in Figure 7 represent the time just after the start of the release near the center of the measurement grid at 19:15 GMT. The righthand plots represent the full strength of the release at

19:20 GMT, including the windswept plume due to a 1.9 m/s wind out of the southwest.

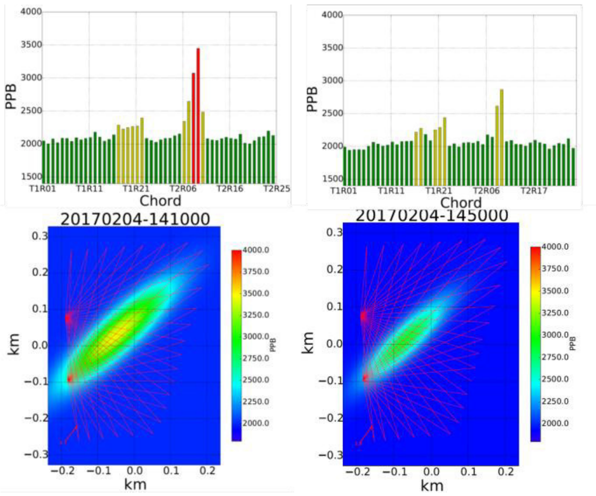


Figure 7: A GreenLITE™ collection of CH_4 during a controlled release at the Harris Farm Test Site (Top ppb), along with corresponding 2-D reconstructions (bottom ~0.4 km W X 0.6 km H).

4 CONCLUSIONS

The GreenLITE™ instrument has demonstrated reliable autonomous operation, measuring CO_2 over the city of Paris, France, for a one-year period. The differences in the GreenLITE™ measurements and the independent in situ measurements are comparable to comparisons between the in situ instruments themselves, which is promising but not sufficient for validation. Further examination of the data set, including combinations with additional information such as boundary layer height and 3-D wind fields, or direct insertion into existing inversion schemes, are planned for the coming year.

Recent experiments have demonstrated the ability of the GreenLITE™ measurement concept to be applied to CH_4 measurements by clearly capturing a controlled release at the Harris Farm Test Site.

We are currently seeking opportunities to participate in validation efforts focused on determining the absolute accuracy of the open path measurements and the 2-D reconstructions for both CO_2 and CH_4.

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