Atmospheric Monitoring of Methane Leaks from Shale Oil and Gas Production Using Airborne Near-Infrared Spectrometer

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INTRODUCTION

Background Information

- To quicken recovery rates and increase extraction yields of natural gas, hydraulic fracturing has become common practice.
- Methane, a major component of natural gas, is released into the atmosphere through extraction, transportation and storage in the form of fugitive emissions and blowback during the fracturing process.

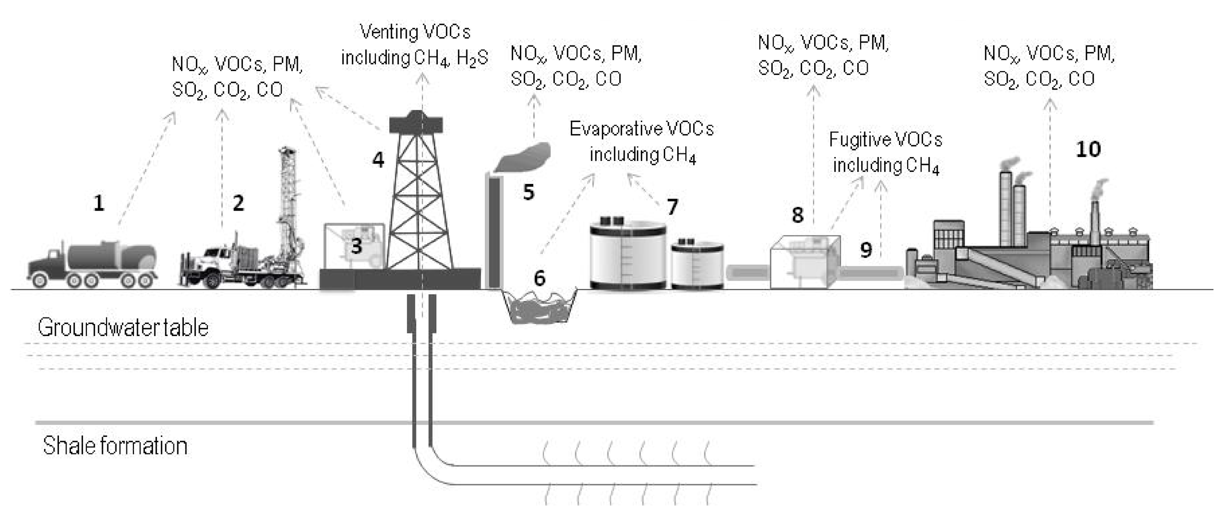

Figure 1: Sources of methane emissions during fracturing process

- Two large natural gas reservoirs, the Utica and Marcellus shale formations, line much of the eastern border of Ohio and numerous well sites are centered in this area. Spatially these drill sites are located over hundreds of miles.

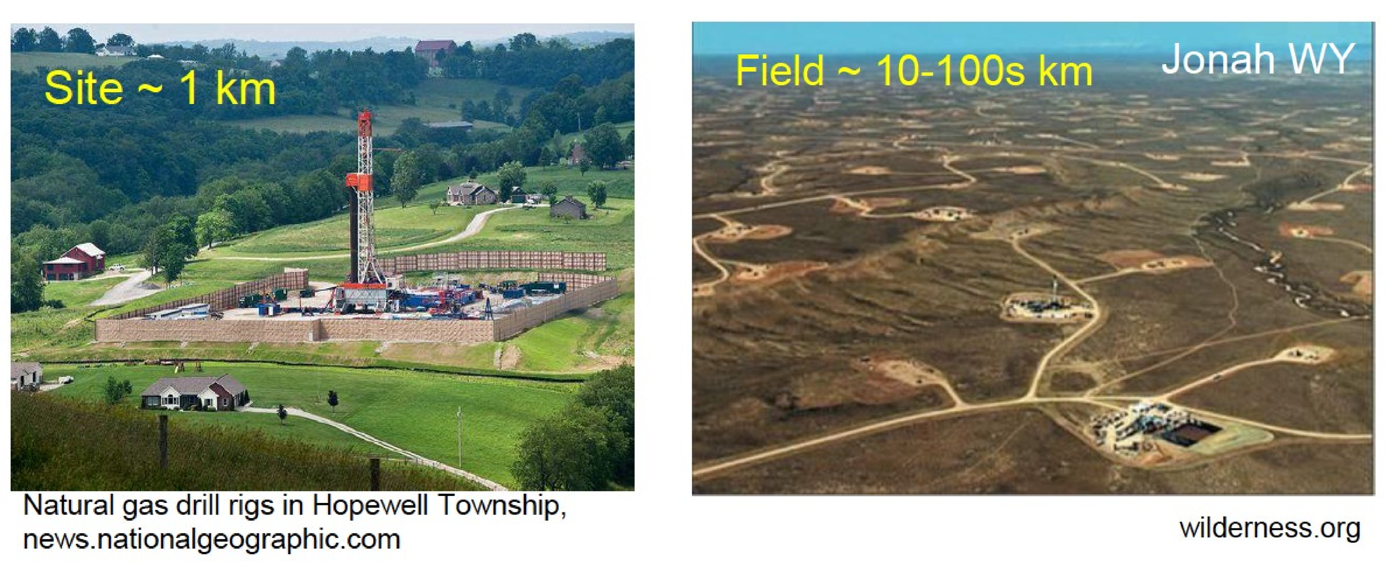

Figure 2: Spatial Scale of drilling activities in shale formation. Source Robinson (2012)

- These spatial demands eliminate the singular use of stationary ground instruments and necessitates the use of remote sensing that can cover large areas.

Objective

- This work proposes remotely monitoring atmospheric methane concentrations through the use of a custom (1.61-1.68 μm) shortwave-infrared (SWIR) spectrometer via aircraft travelling over known areas of shale activity.
- The Moderate Resolution Transmission (MODTRAN®) radiative transfer model is introduced and an early assessment of it's capability to quantify methane concentrations for future work was performed.

Passive Remote Sensing

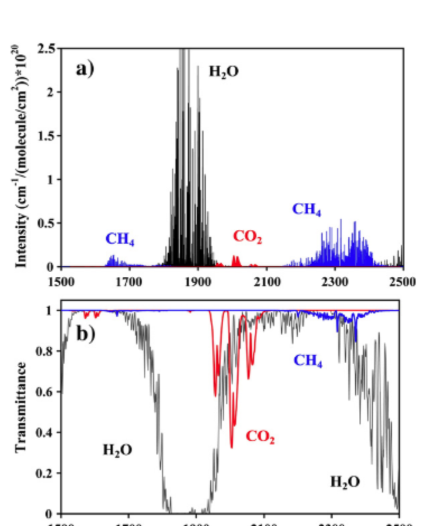

Figure 3: Spectral intensity (top) and atmospheric transmittance spectra (bottom) for various gases including methane. The absorption bands show two peaks of CH_4 at 1.6 μm and 2.3 μm. However, CH_4 peak at 2.3 μm consists of interference due to water vapor absorption. Therefore, absorption peak at 1.6 μm is ideal, though small, to eliminate interferences from H_2O and CO_2 absorption bands. Source: Roberts et al. (2010)

- Two types of remote sensing via aerial platform: passive and active
- Passive uses reflected sunlight while active uses direct light source such as lidar.
- Passive remote sensing has to account the varying light intensity due to diurnal solar radiation, albedo, cloud cover and other environmental parameters.
- Generally, passive remote sensing is supported with radiative transfer models that accounts the loss of light due to all these parameters

Methodology

Flight Experiments

- In this study a BaySpec SWIR spectrometer is used aboard a Beechcroft Baron 58. The spectrometer has been customized so that it's sensor will detect wavelengths between 1.61 μm and 1.68 μm.
- The sensor has a field of view of 40˚ and 5˚ in the vertical and horizontal planes. Which when flying at an altitude of 1000 feet results in a pixel resolution of 728 x 87 feet.
- During flight a 10 cm opening was made in the exterior of the aircraft and the spectrometer was mounted so that the sensor had an unobstructed view pointing downward towards the Earth's surface*.

Figure 4: Image of the Beechcroft Baron 58 provided by the Aviation Engineering Center for flight experiments

Figure 5: Customized SWIR spectrometer used during flight experiment (left), configuration of spectrometer inside aircraft (right)

- The aircraft then flew over known areas of major shale activity where elevated concentrations of methane would be expected to be present.
- A strong peak in the absorbance spectrum at 1.66 μm indicates the presence of methane which can then be correlated to it's atmospheric concentration in the column underneath the aircraft.

Modeling

- There are several varying conditions experienced in remote sensing applications; aerosols, cloud cover, sensor geometry, surface properties, and atmospheric pollutant concentrations. The Moderate Resolution Atmospheric Transmission (MODTRAN) allows users to control for these variables.

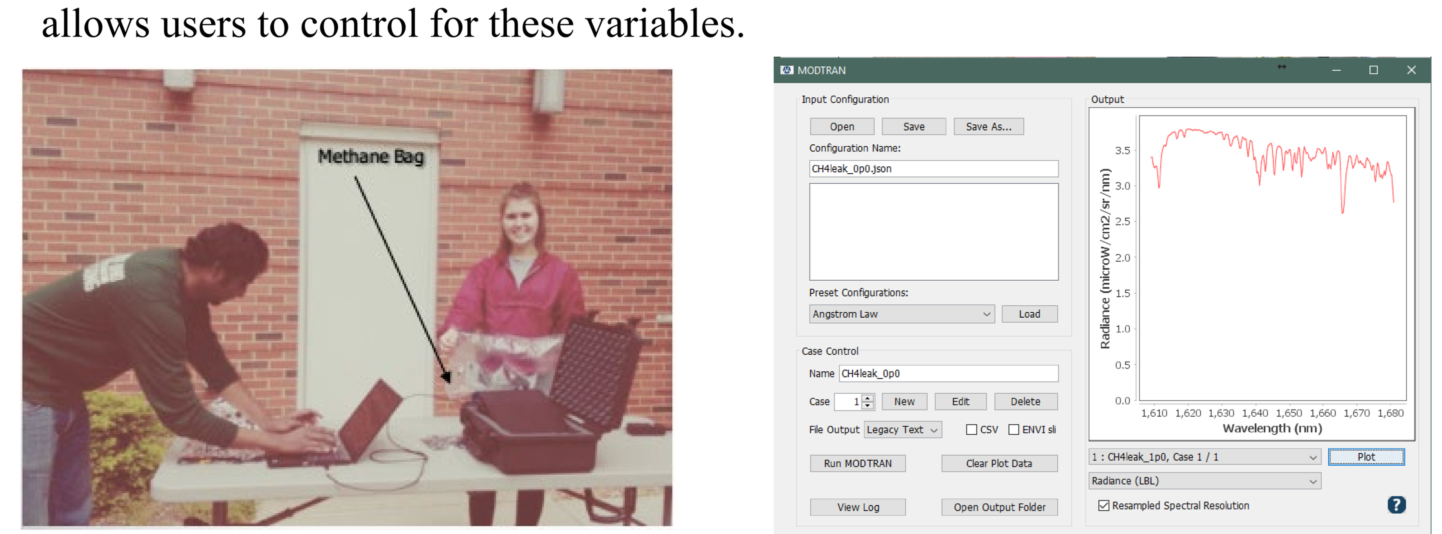

Figure 6: Graphical user interface of MODTRAN (right), and ground experiments with spectrometer (left).

- If the model can match all other flight conditions, because it's level is controlled in the model, atmospheric concentrations of methane can be quantified.
- Preliminary experiments tested MODTRAN's capabilities by comparing calculated absorbance spectra to absorbance spectra produced by the spectrometer at ground level using plastic bags filled with methane.

RESULTS

Ground Calibration

- The MODTRAN absorbance spectrum displays a distinct peak in absorbance at 1.66 μm similar to spectral data from the instrument in the ground test.
- The peak , and less significant absorbance magnitudes between the two spectra are not identical but that should be expected.
- Figure 7 shows a preliminary indicator that MODTRAN is a potential candidate for future work in quantifying methane concentrations.

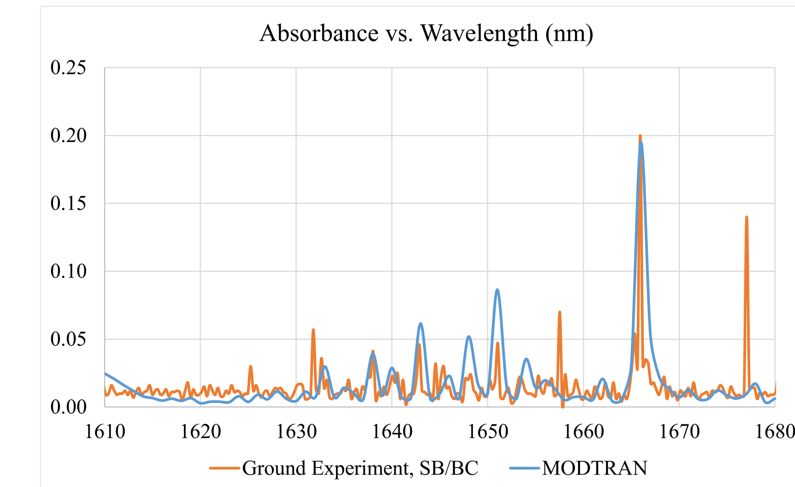

Figure 7: Comparison of results from ground tests performed on campus to an absorbance spectrum produced by MODTRAN using Athens atmospheric conditions, and solar geometry.

Flight Experiment

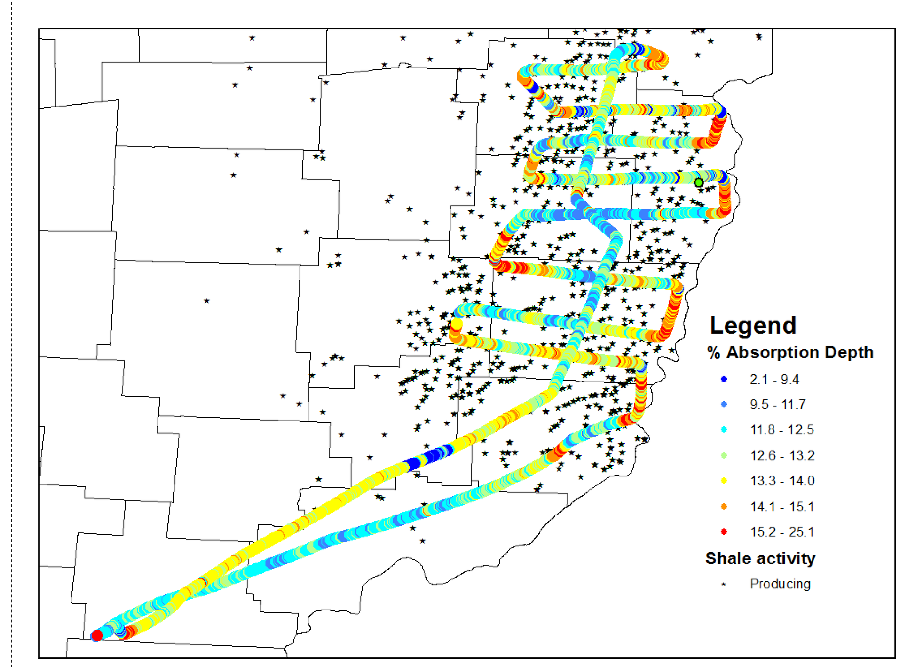

Figure 8: Airborne spectral measurements over shale activity in Ohio. The % absorption depth was computed from radiance spectra at two wavelengths of 1663.97 nm and 1665.933 nm. This dataset provide the relative increase in CH_4 column concentrations during airborne flight. High values (red) indicates potential high methane releases.

- The instrument largely depends on the amount of reflected light from the surface
- The intensity signal fluctuates with the amount of light and therefore, CH_4 absorption cannot be extrapolated directly
- A relative % difference between two wavelength is therefore used to obtain relative absorption at each point

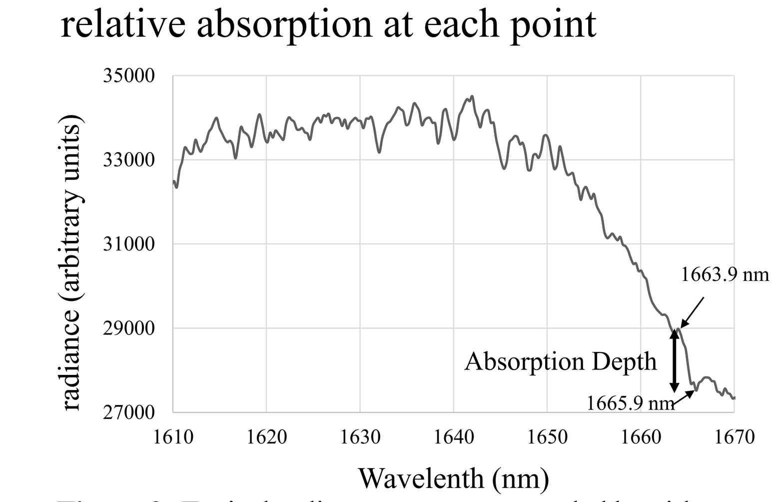

Figure 9: Typical radiance spectrum recorded by airborne instrument. The peak absorption occurs at 1665.9 nm. The absorption depth is calculated from the difference between radiance intensities at 1663.9 nm and 1665.9 nm.

Future Tasks

- Future tasks will be dedicated to quantifying methane concentrations. In order to do so acquiring more data from the spectrometer in-flight will be necessary. This allows:
  - Further evaluation of the MODTRAN model. If MODTRAN can be precisely tuned to match flight operating conditions, concentrations of methane near shale well sites can be quantified.
  - Improvement in methods of operation leading to enhanced spectrometer performance, and overall procedural efficiency.
- In many remote sensing applications, data is often presented in radiance values. Currently the Spec 2020 software coupled with the spectrometer only has the capability to produce radiance intensity in arbitrary units. Therefore, the spectral data will be calibrated with MODTRAN simulations using relative absorption depth (discussed above) and generate methane concentrations above background level.
- With affordable access to the test flights in the Avionics Engineering Center and expertise in air quality, Ohio University is uniquely positioned to investigate the methane emissions from shale oil and gas exploration using airborne remote sensing measurements.

Acknowledgements

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