Characterization and Application of an Improved Quantum Cascade Laser Atmospheric Ammonia Sensor System

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1. Motivation/ Background

- Atmospheric ammonia (NH_3) is a gas-phase precursor to fine particulate matter, which is harmful to both the environment and human health [1]
- Anthropogenic atmospheric ammonia has tripled in the past 200 years [2]
- We developed and deployed an improved compact, open-path atmospheric ammonia sensor system using a Corning quantum cascade (QC) laser to accurately detect ambient ammonia levels in the Princeton, NJ area

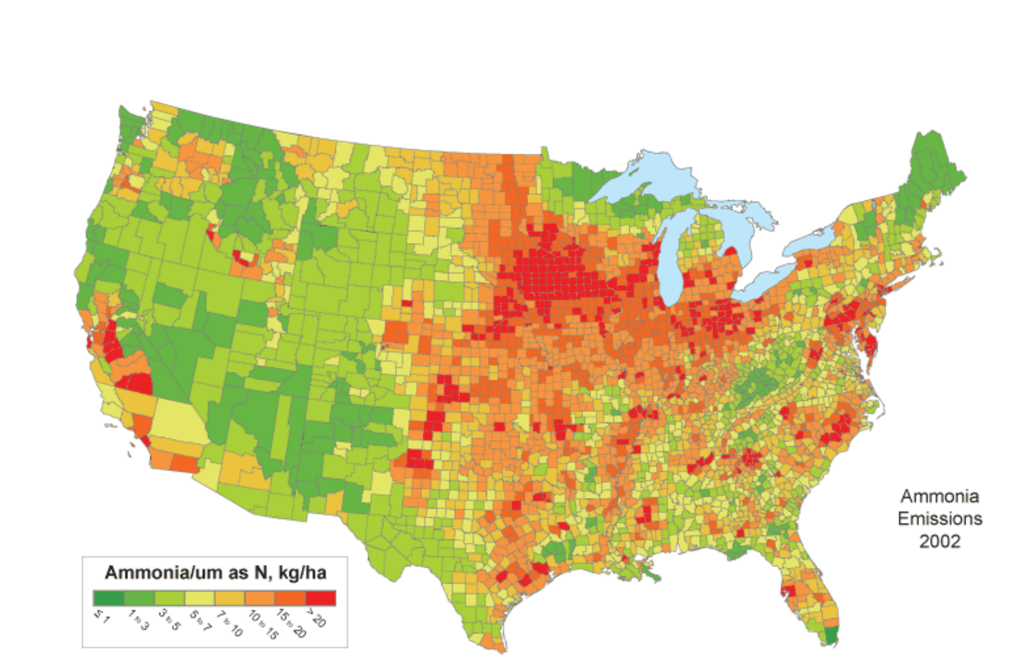


Fig. 1: Atmospheric ammonia emissions in the U.S. from all sources, 2002 [3]

2. Methods

- We placed a Corning QC laser in an existing ammonia sensor system with an in-line ethylene reference cell
  - 53°C operating temperature, 380-580mA current tuning range
  - Ammonia detection (absorption spectroscopy) at wavelength of 9062nm with a 42m path length
- We deployed the sensor at a construction site in Princeton, NJ over a 2-day period
- Ammonia (NH_3), ethylene (C_2H_4) reference signal, as well as detector signal strength, air temperature, relative humidity, and wind speed/direction measurements were taken

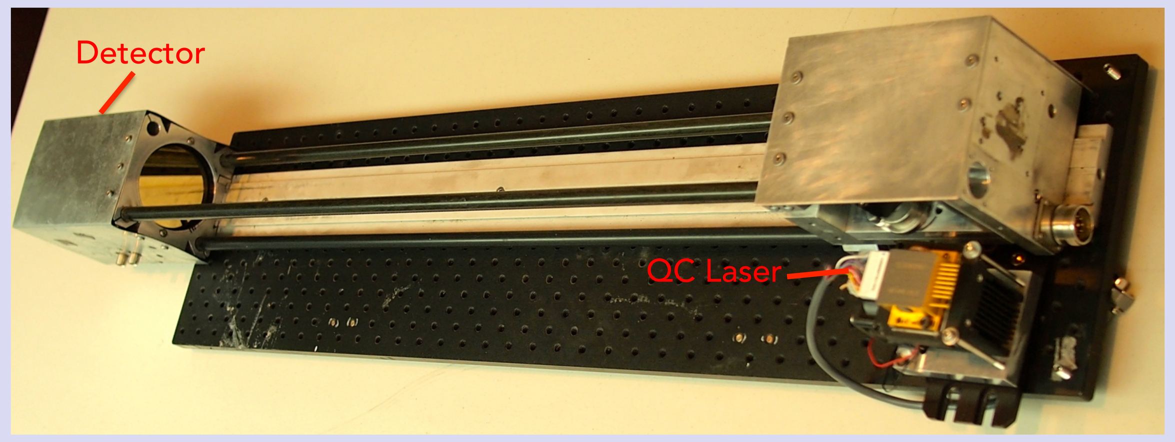


Fig. 6: Entire sensor system

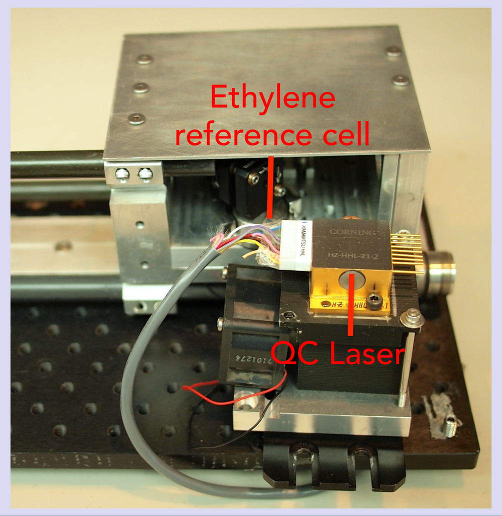
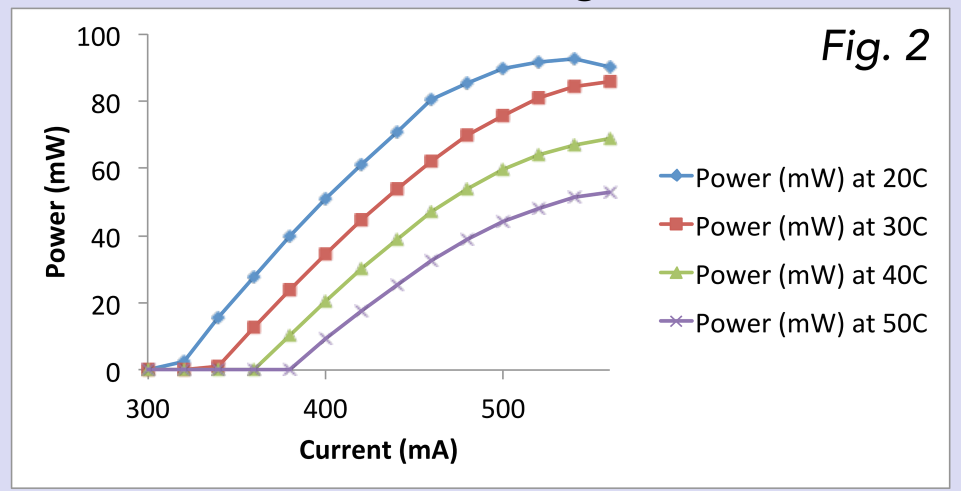
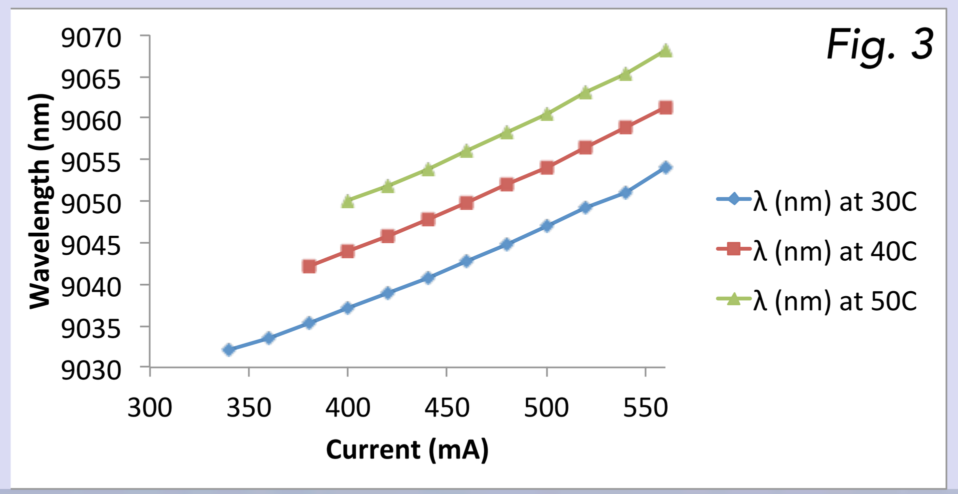


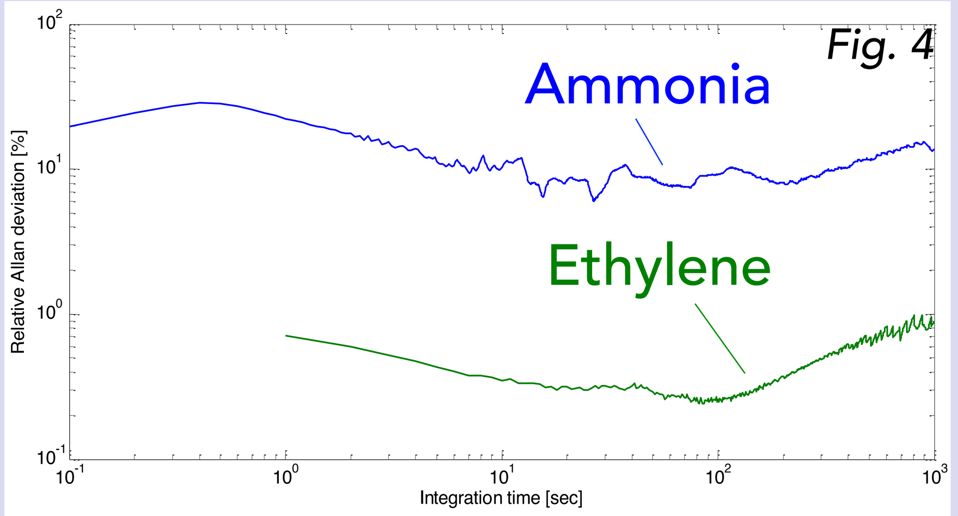
Fig. 7: Close-up of QC laser

3. Laser Characterization

- Determined laser's optimal wavelength for ammonia detection
  - Step 1: Controlled laser current/temperature and measured power emitted (*Fig. 2*)
  - Step 2: Controlled laser current/temperature and measured wavelength output (*Fig. 3*)
  - Step 3: Conducted Allan variance plot to determine the accuracy of our laser as compared to outside noise in the lab (*Fig. 4*)







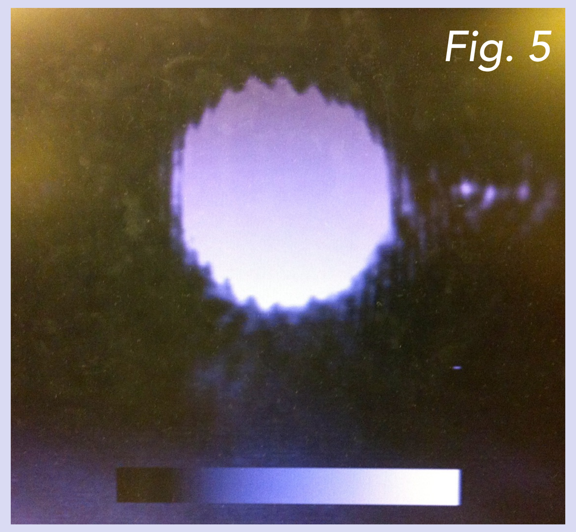
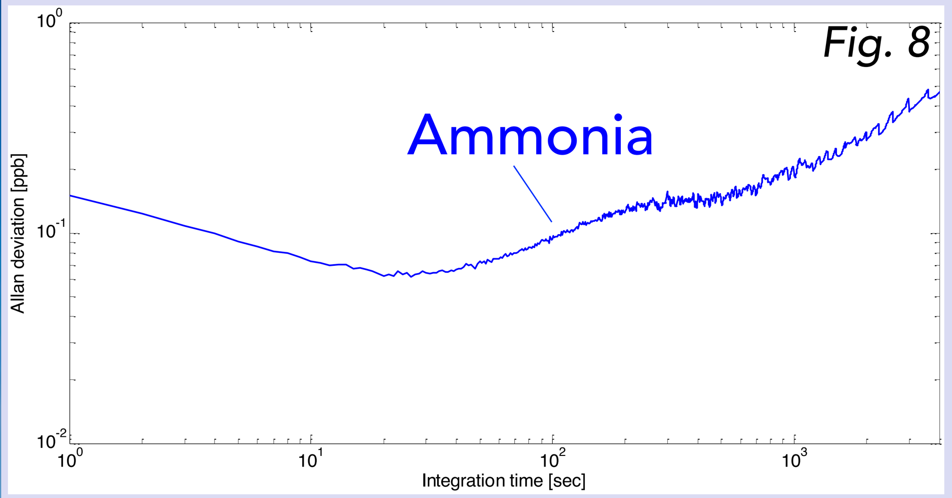
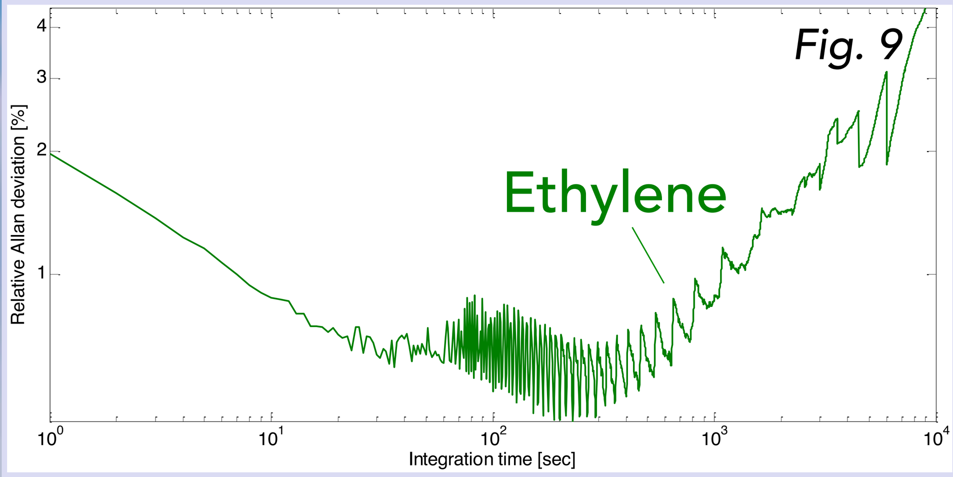


Fig. 2: Laser current (milliamps) versus optical power output (milliwatts)
Fig. 3: Laser current (milliamps) versus wavelength output (nanometers)
Fig. 4: Allan variance plot in laboratory. Ammonia is recorded at 10Hz and ethylene is recorded at 1Hz. Ammonia concentration was changing in the laboratory
Fig. 5: IR camera photograph of laser beam at 5cm distance from laser

4. Results

- The average weather conditions during the deployment were: 30.82°C, 57.84% relative humidity, 1.27 m/s wind speed
  - Hot temperatures, variable wind





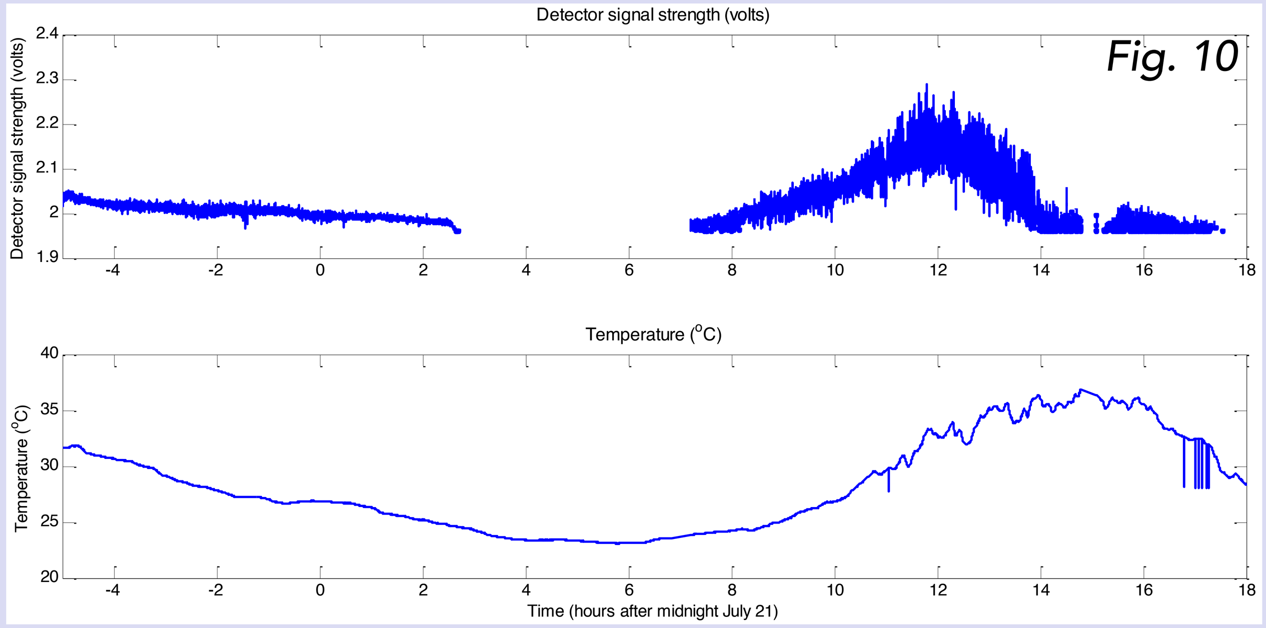


Fig. 8: Allan variance plot of ammonia during field testing. Includes atmospheric variability.
Fig. 9: Allan variance plot of ethylene during field testing showing 2% precision at 1 second; precision is maintained through an hour
Fig. 10: Detector signal strength (top) and temperature (bottom) measurements during field testing; signal strength was relatively stable and changed by ~10% during the testing period

5. Conclusions/ Future Work

- The previous ammonia sensor system in operation had a wavelength tuning range of approximately 5nm, while the new sensor has a wavelength tuning range of up to 20nm at high operating temperatures (50°C), allowing for more sensitive measurements
- We demonstrated high stability of the ethylene reference signal in the lab and under field conditions with the newly integrated Corning QC laser
- In the future, we hope to conduct field deployments for longer periods of time

References:

[1] Pinder, RW, AB Gilliland, RL Dennis. Environmental impact of atmospheric NH_3 emissions under present and future conditions in the eastern United States . Geophy. Res. Lett. 35: 25, 2008.

[2] Adams, Peter J., J.H. Seinfeld, D. Koch, L. Mickley and D. Jacob. *General circulation model assessment of direct radiative forcing by the sulfate-nitrate-ammonium-water inorganic aerosol system*. Journal of Geophysical Research. 106: 1097–1111, 2001.

[3] Data source: http://nadp.sws.uiuc.edu/amon/

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